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Hopkins et al.

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(54) **APPARATUS AND METHODS FOR RECOVERING ABRASIVE FROM AN ABRASIVE-LADEN FLUID**

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(73) Assignee: **Flow International Corporation**, Kent, WA (US)

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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(21) Appl. No.: **09/491,684**

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(22) Filed: **Jan. 26, 2000**

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Related U.S. Application Data

(63) Continuation-in-part of application No. 09/383,044, filed on Aug. 25, 1999, which is a continuation-in-part of application No. 09/069,223, filed on Apr. 28, 1998.

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(51) **Int. Cl.**⁷ **B24B 9/00**

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(52) **U.S. Cl.** **451/88; 451/38; 451/40; 451/87**

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(58) **Field of Search** 451/38, 39, 40, 451/75, 87, 88

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Primary Examiner—Eileen P. Morgan

(74) *Attorney, Agent, or Firm*—Seed Intellectual Property Law Group PLLC

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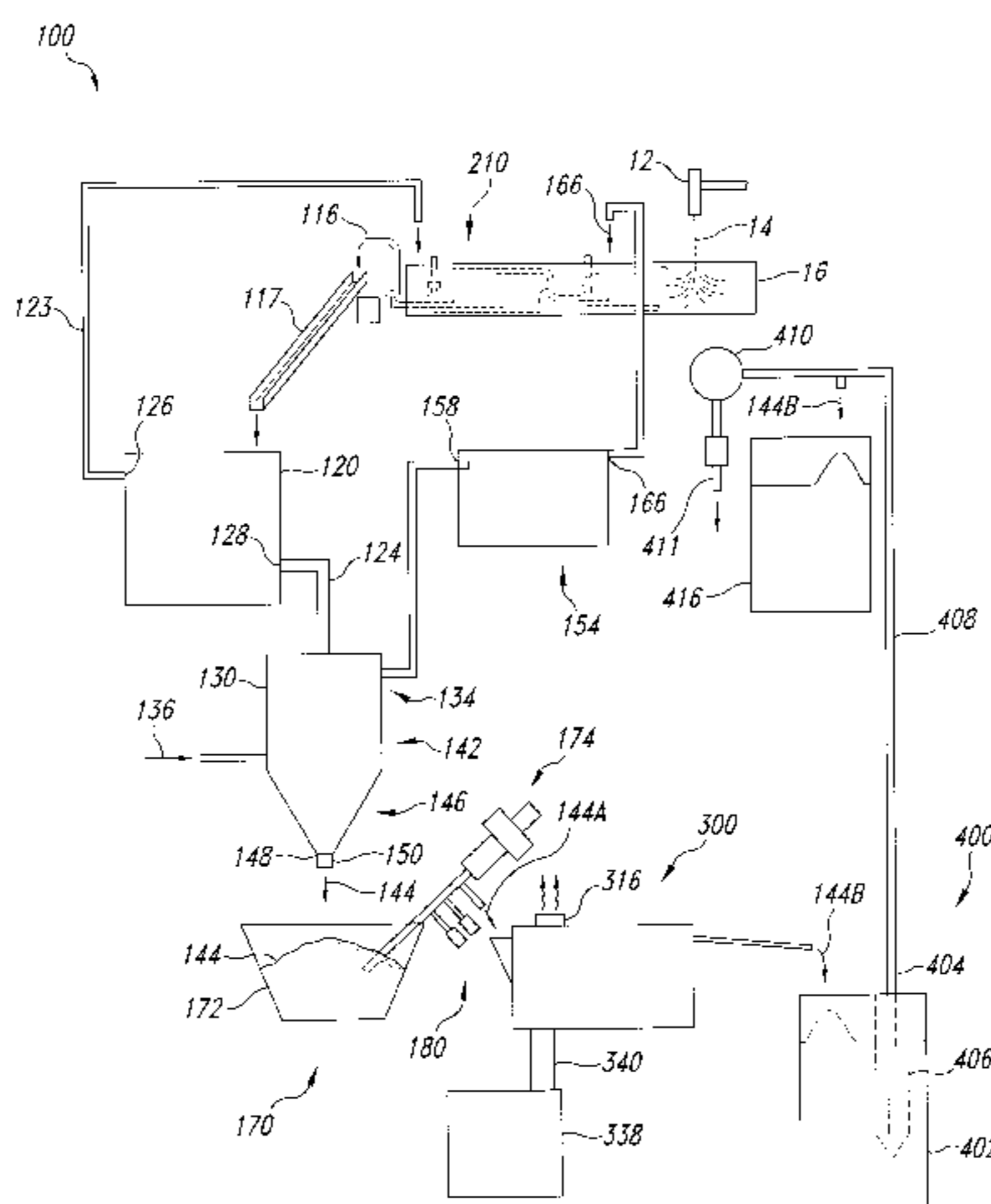
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(57) **ABSTRACT**

An improved apparatus and methods for recovering abrasive from an abrasive-laden fluid are shown and described. An abrasive-laden fluid handling device is coupled to a catcher tank to collect abrasive-laden fluid and transport it to a hydro-classifier. Wet recovered abrasive is discharged from the hydro-classifier and transferred to a de-watering device. The de-watering device removes water from the abrasive by decanting fluid and via use of an air eduction system. De-watered abrasive is then ejected from the de-watering device to a dryer unit, to be further dried and processed for reuse.

(List continued on next page.)

13 Claims, 17 Drawing Sheets



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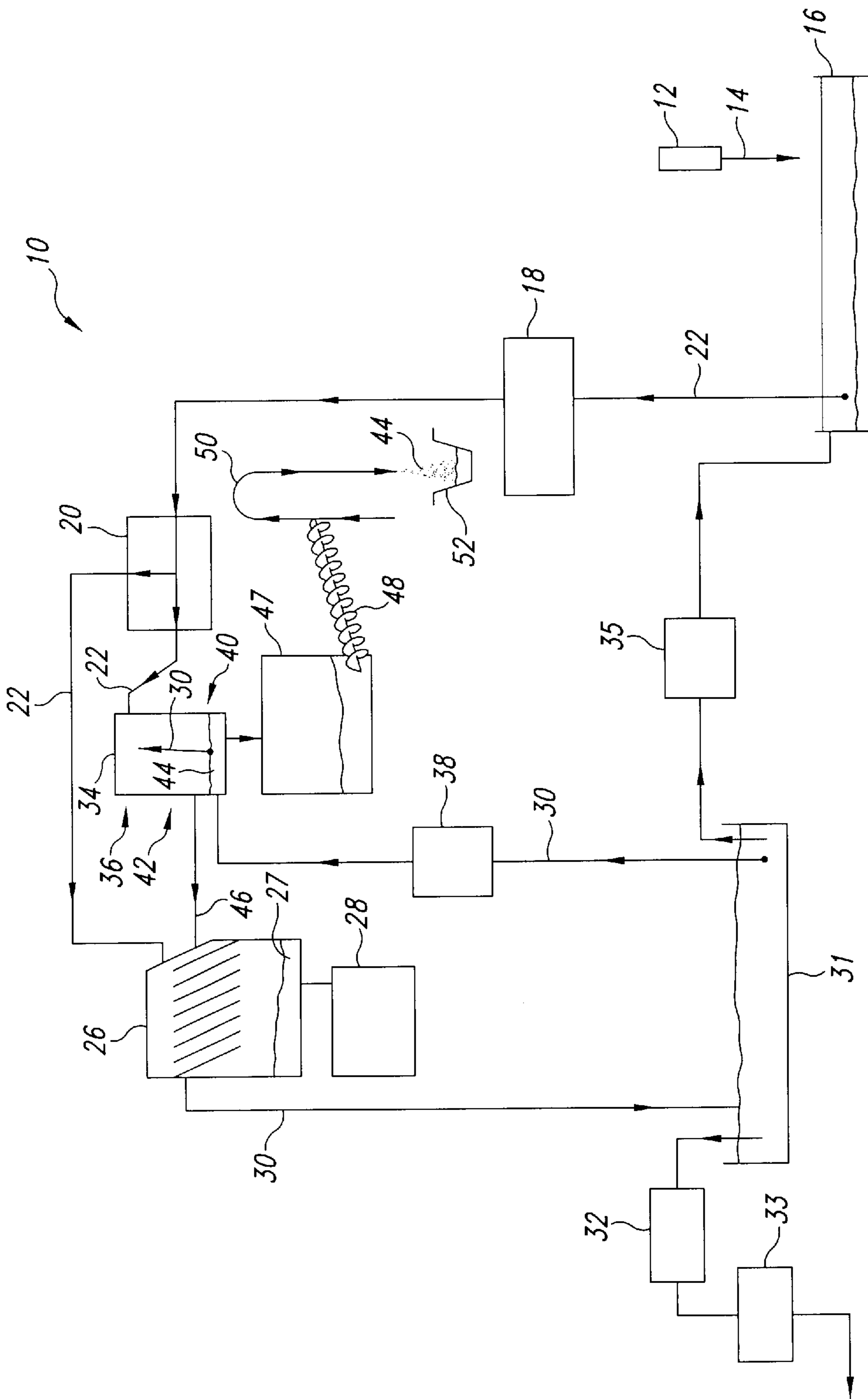


Fig. 1
(Prior Art)

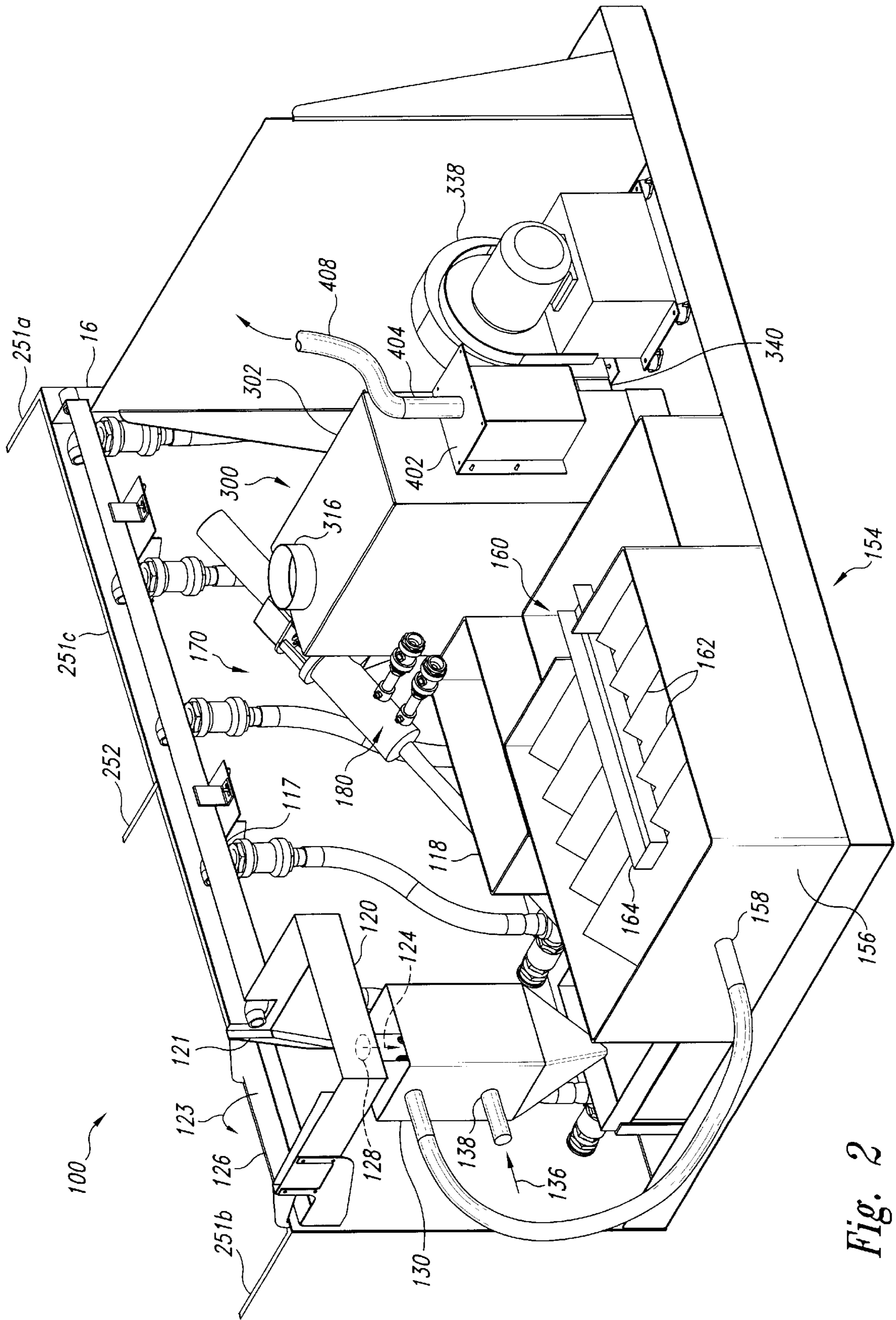


Fig. 2

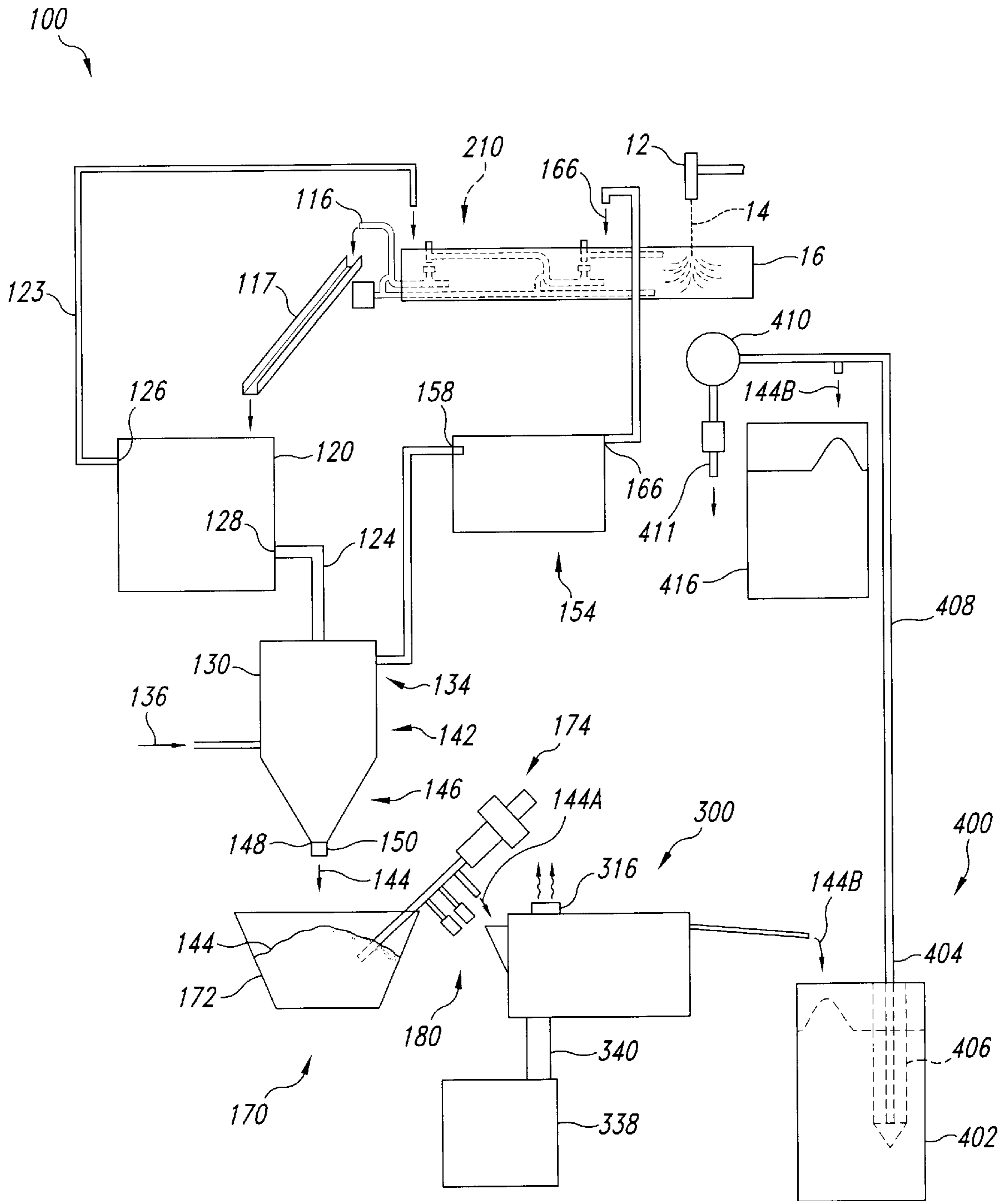


Fig. 3

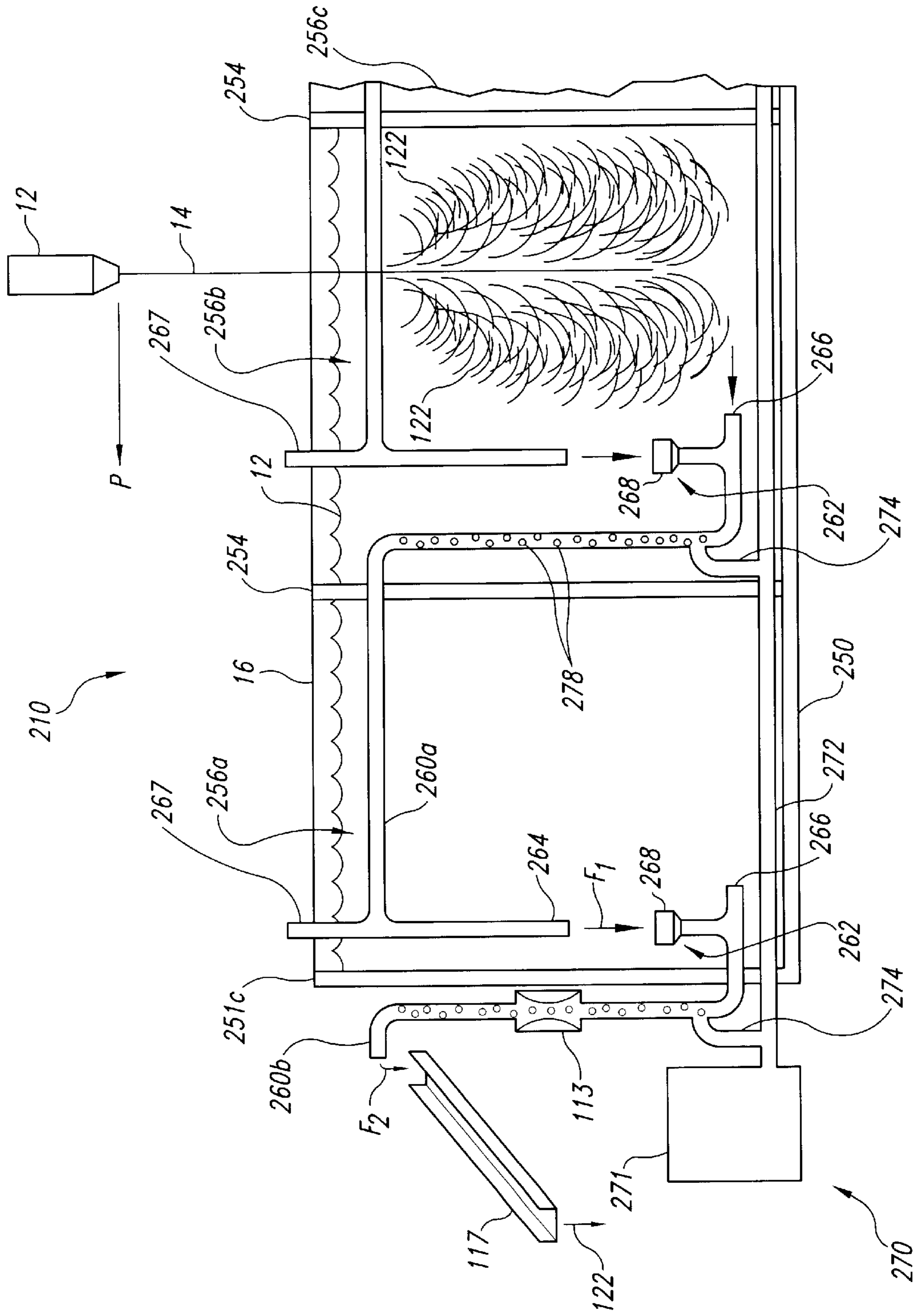


Fig. 4

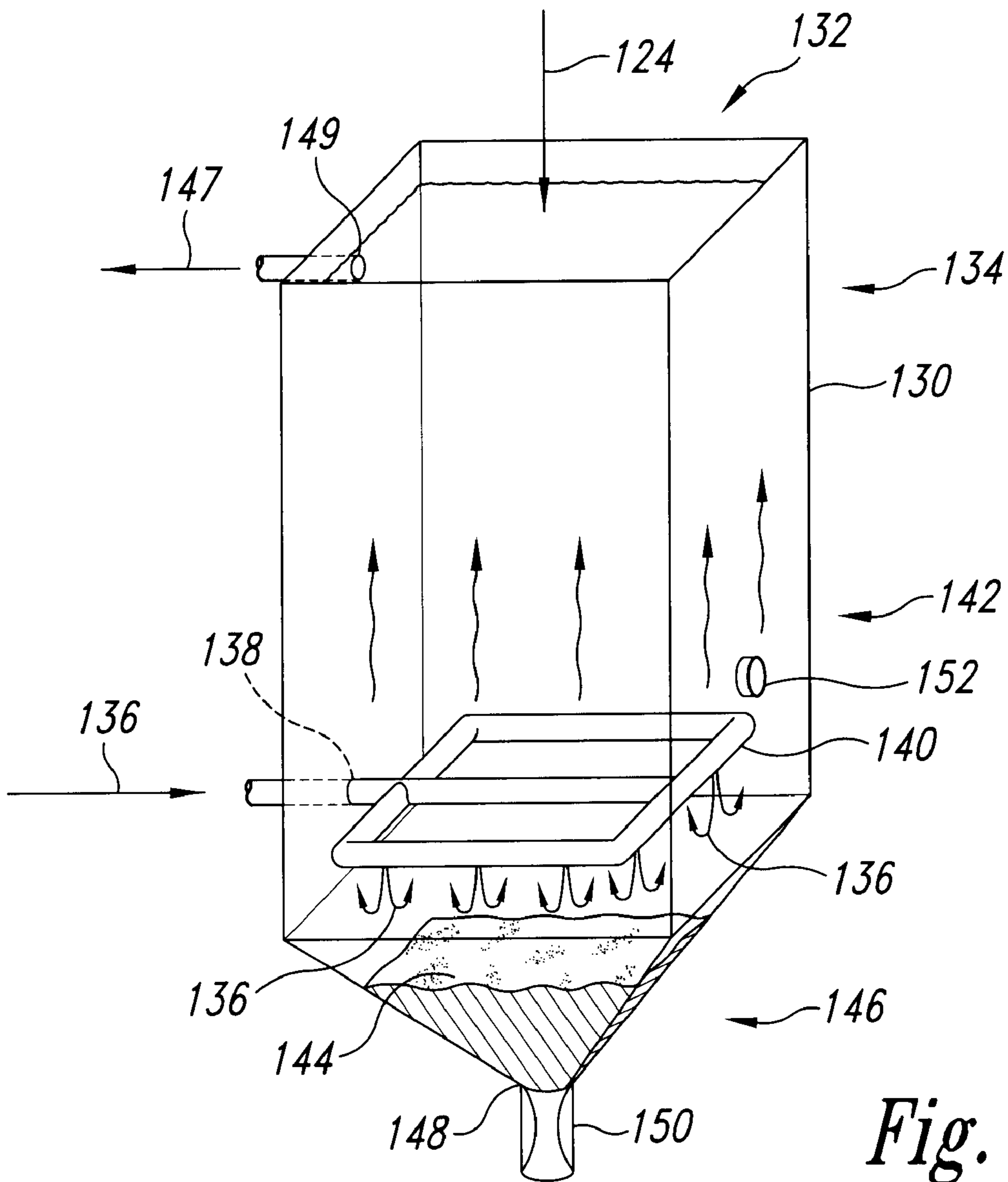


Fig. 5

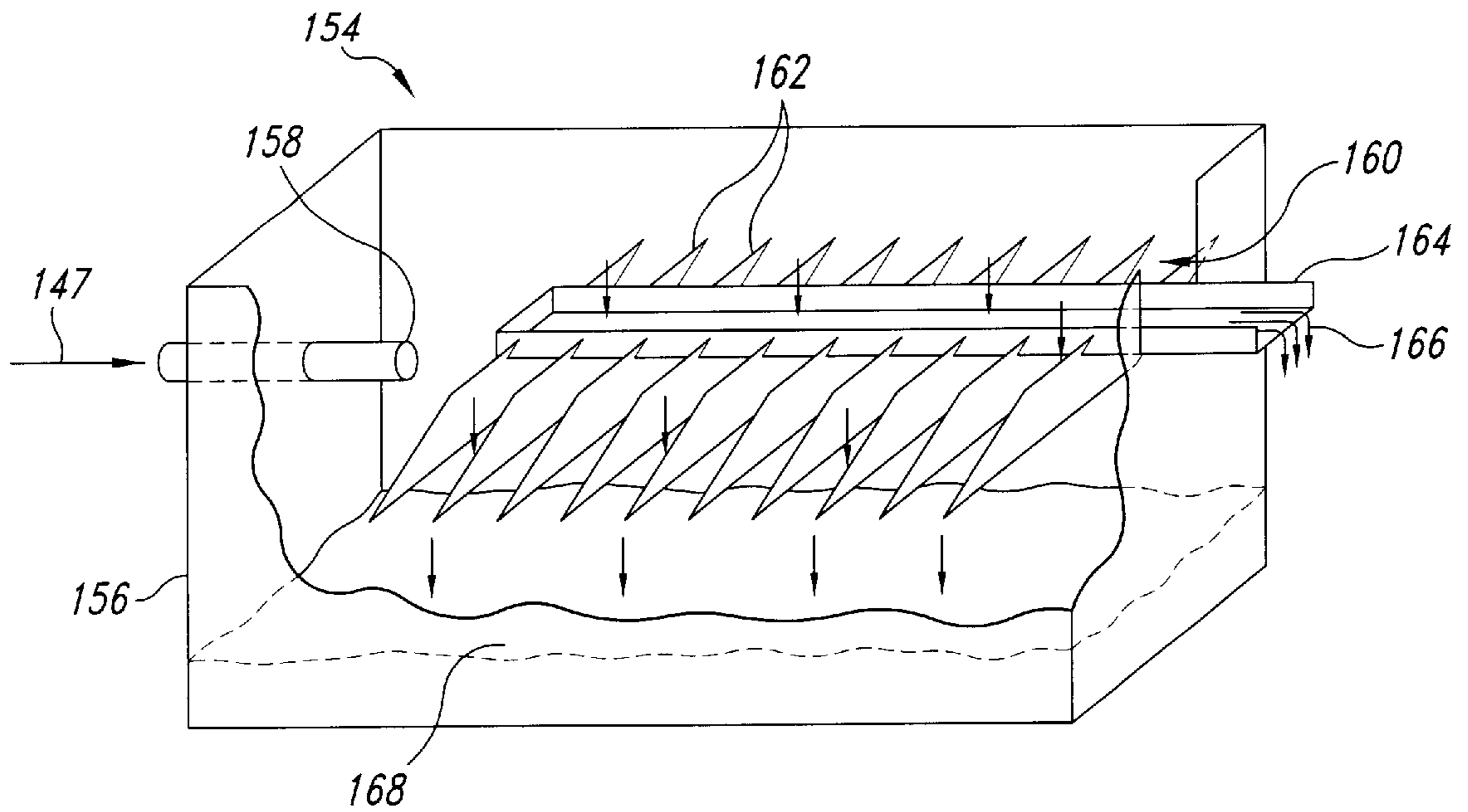


Fig. 6

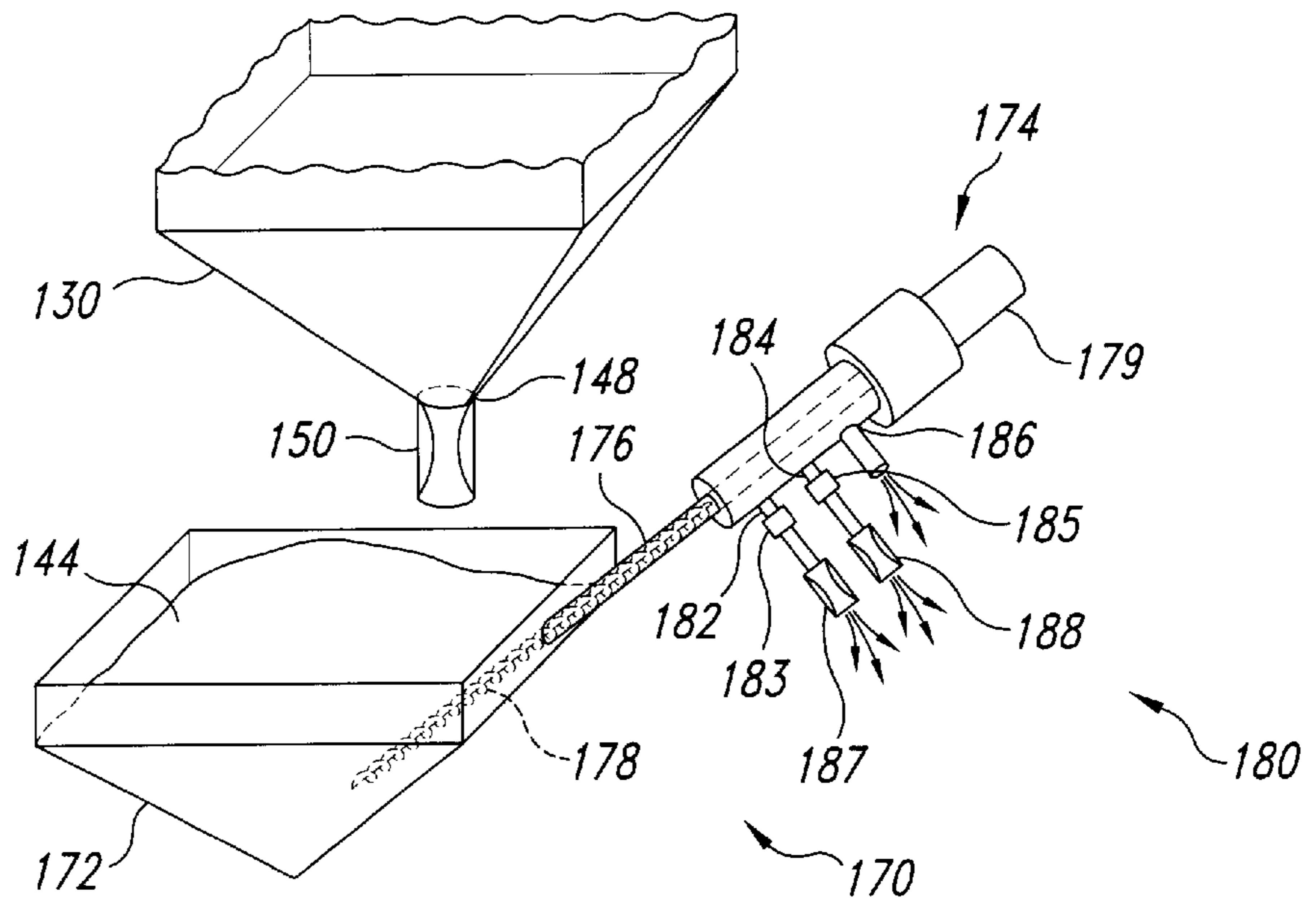


Fig. 7

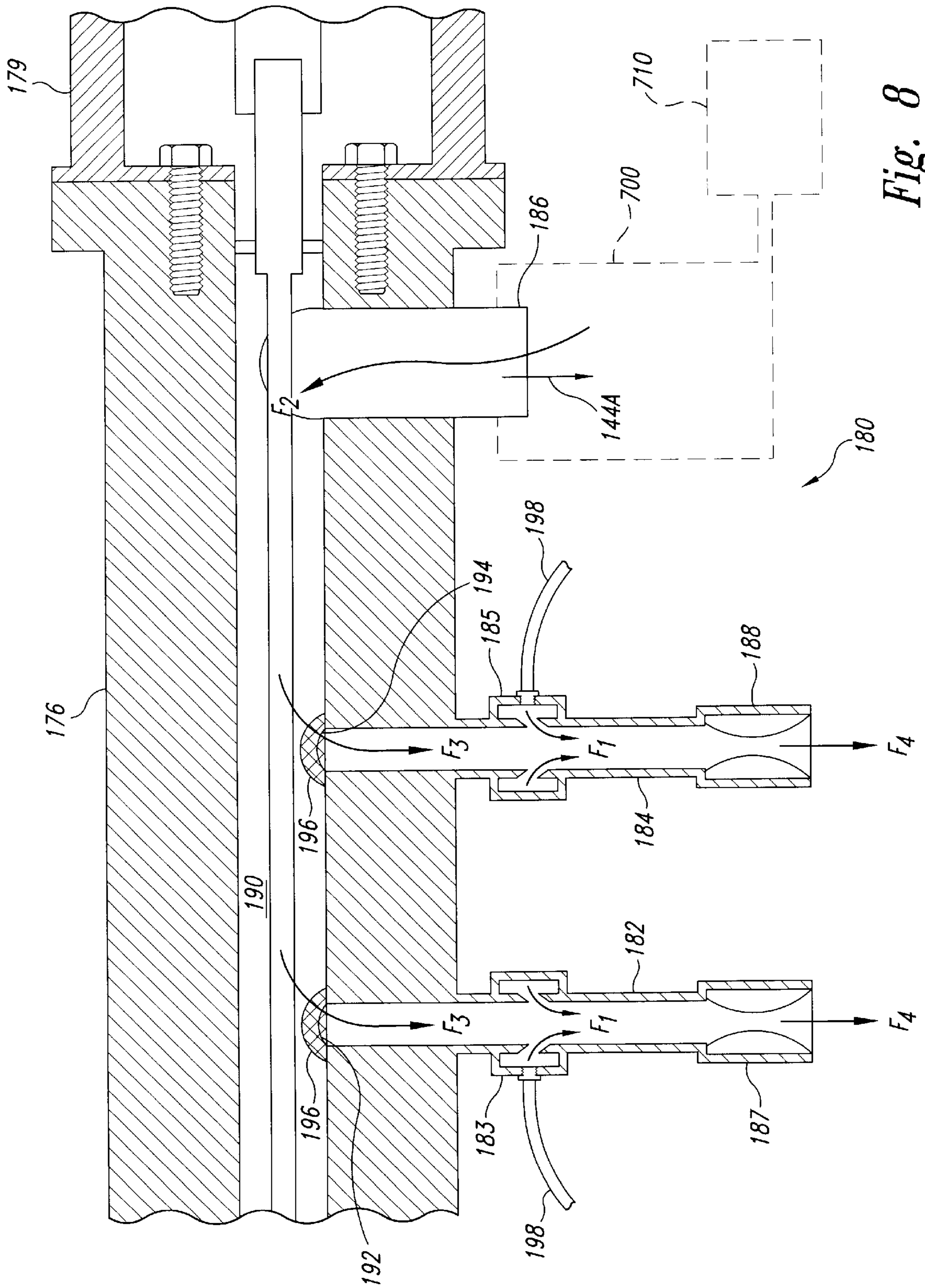


Fig. 8

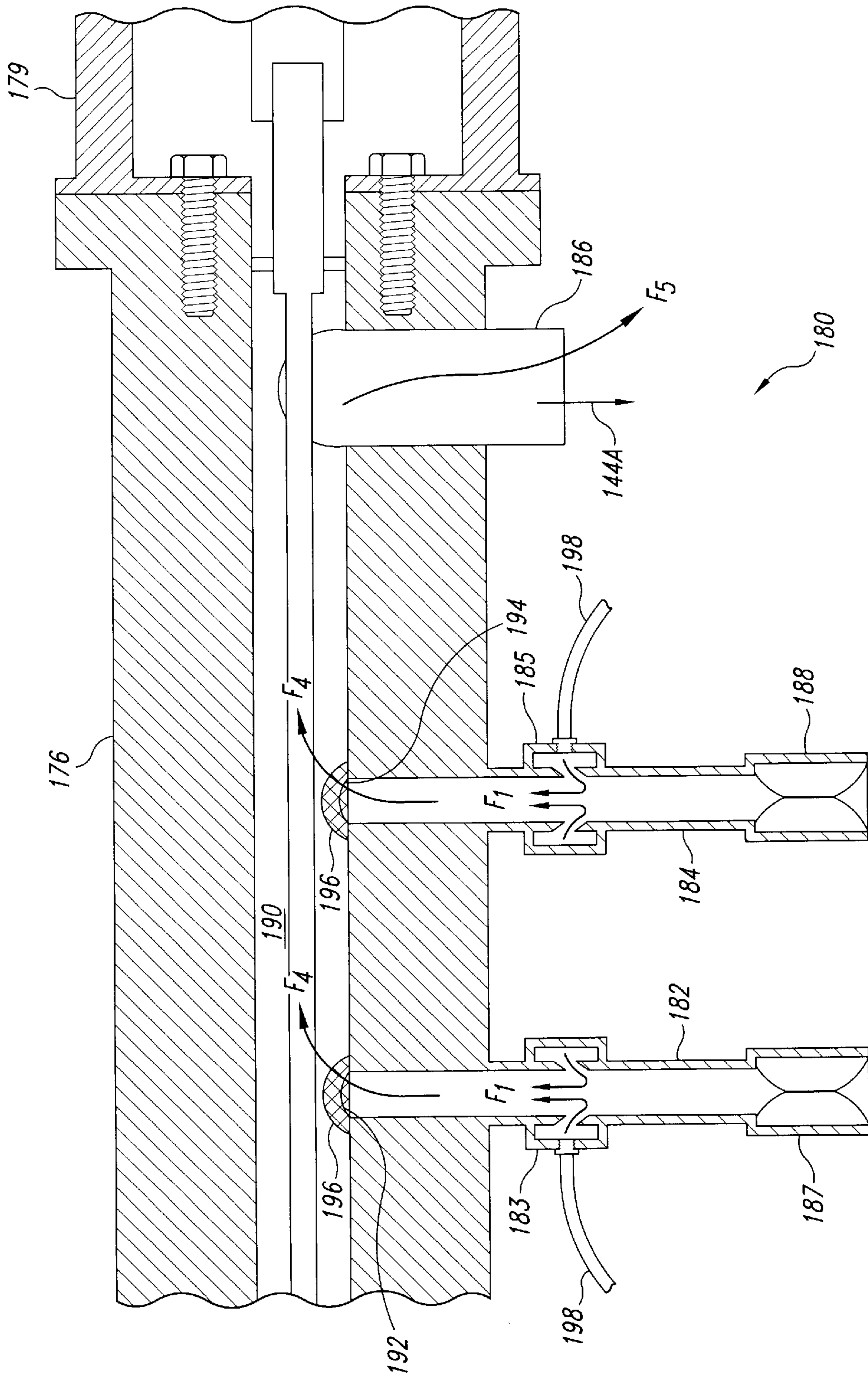


Fig. 9

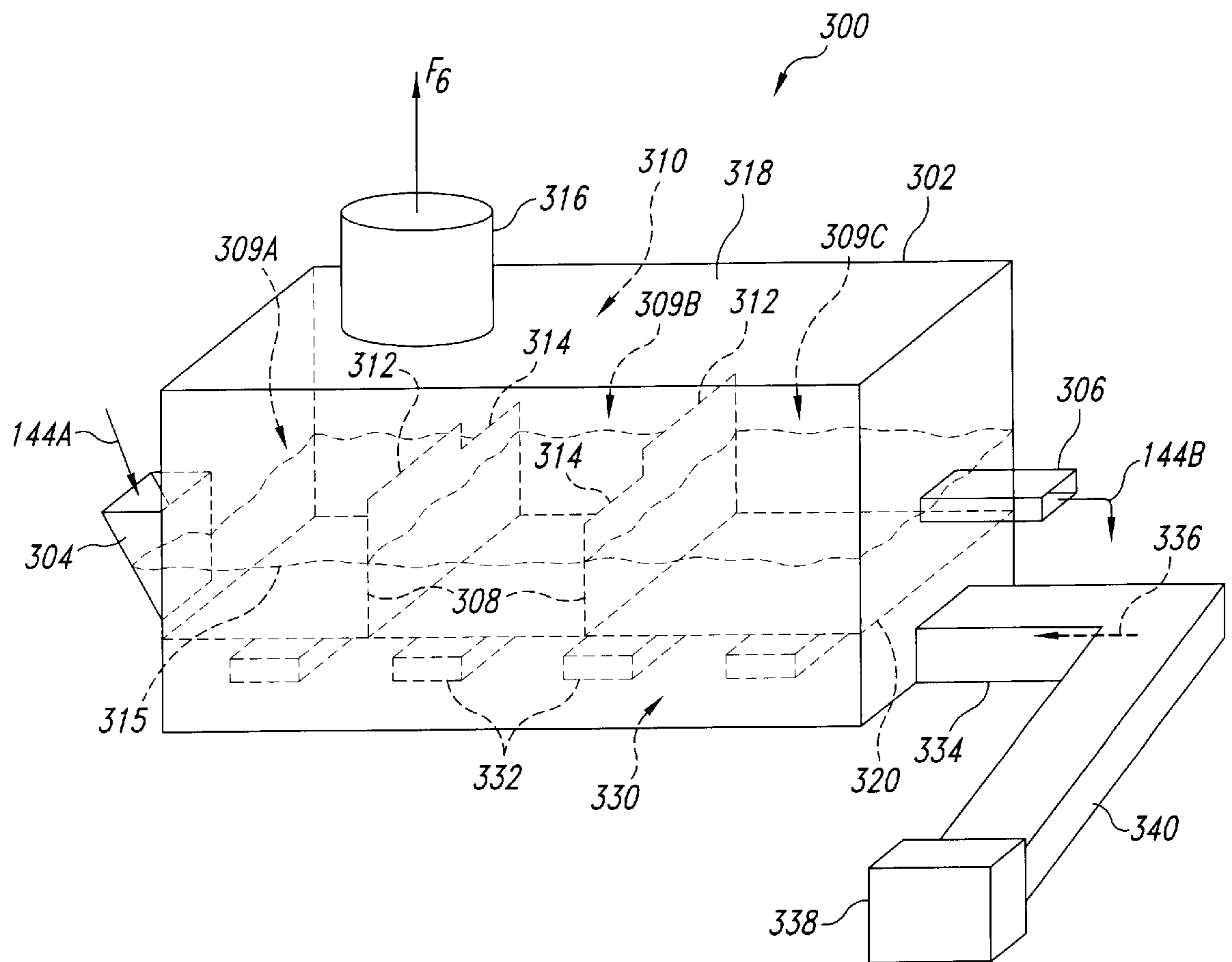


Fig. 10

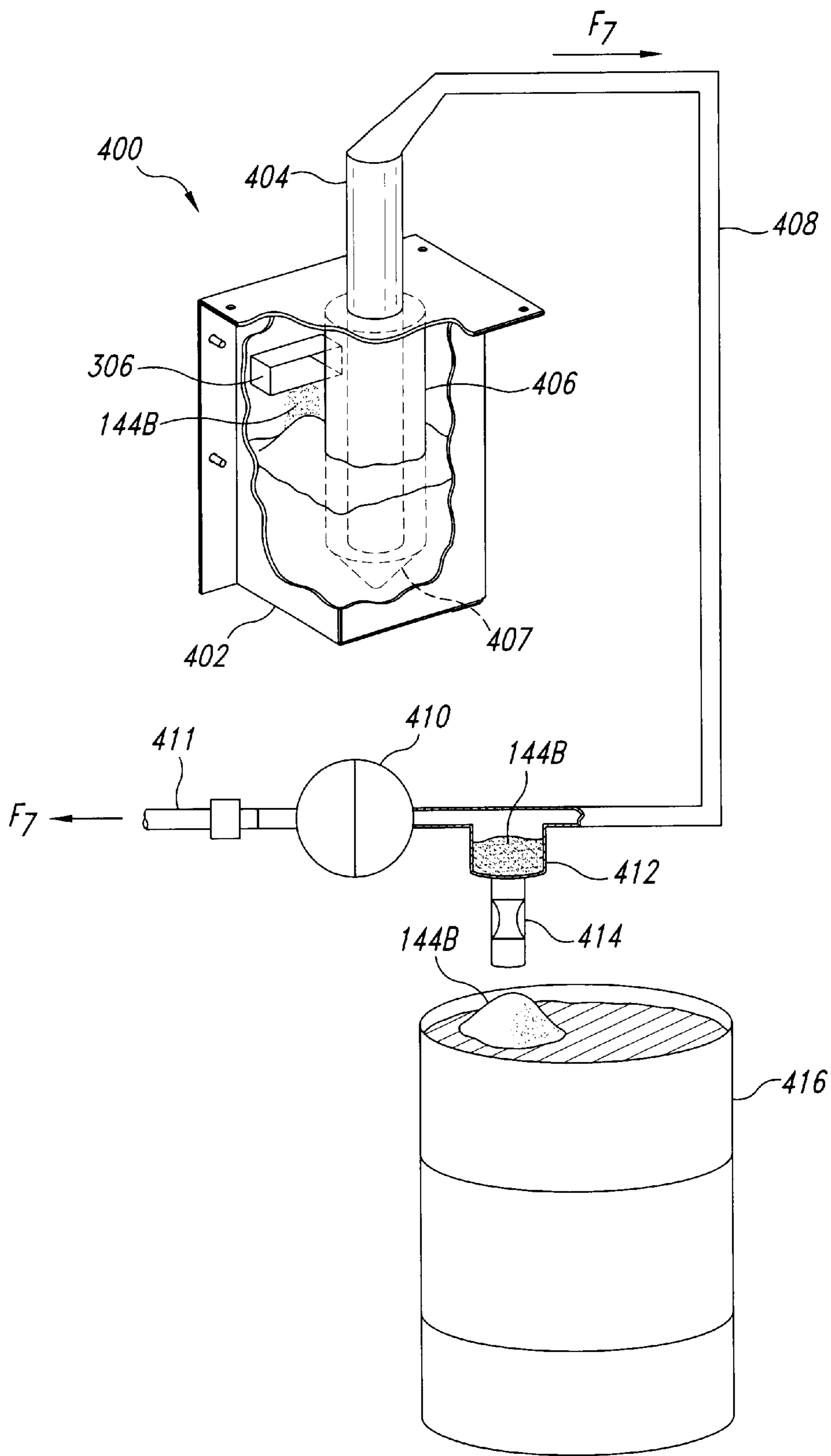
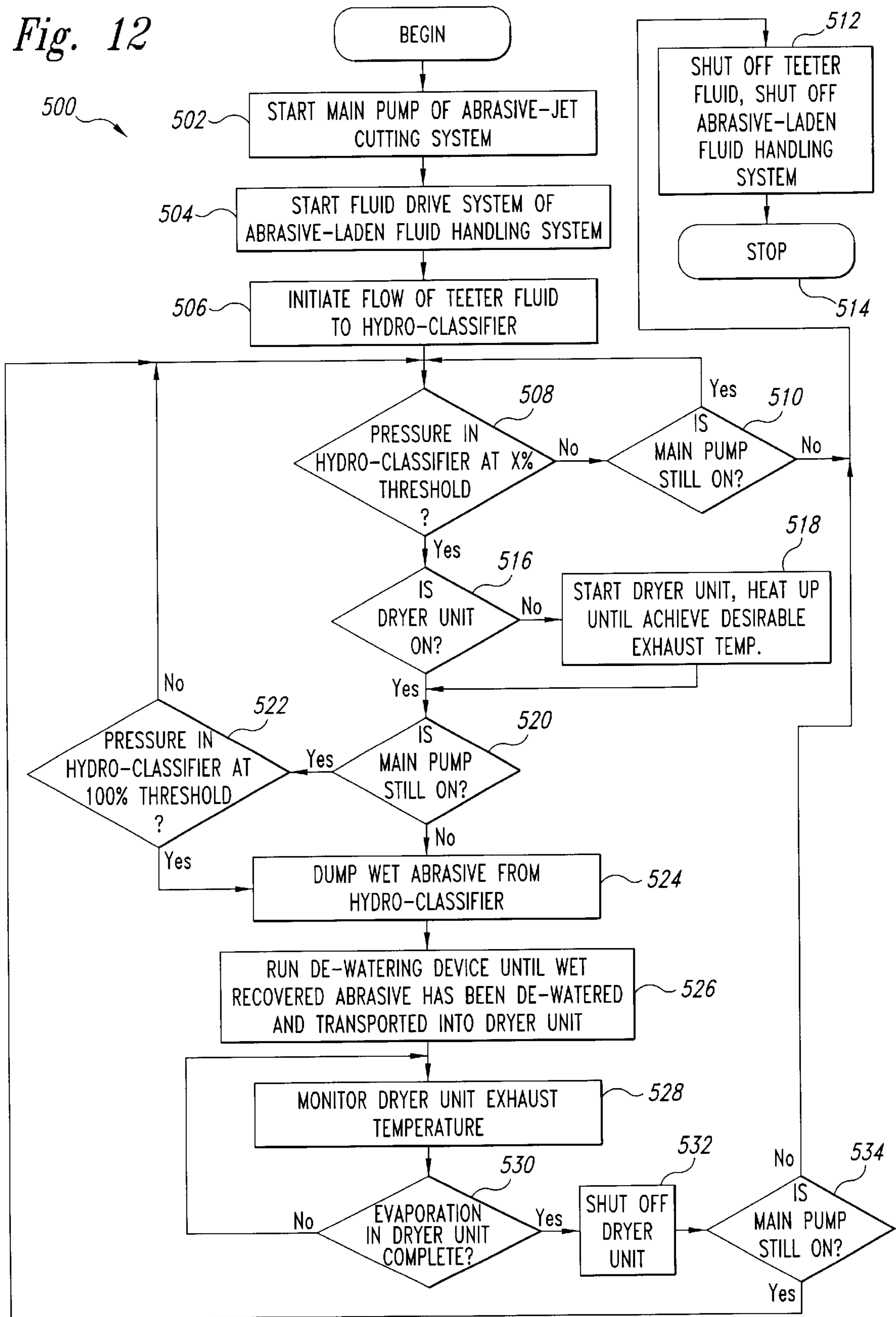


Fig. 11

Fig. 12



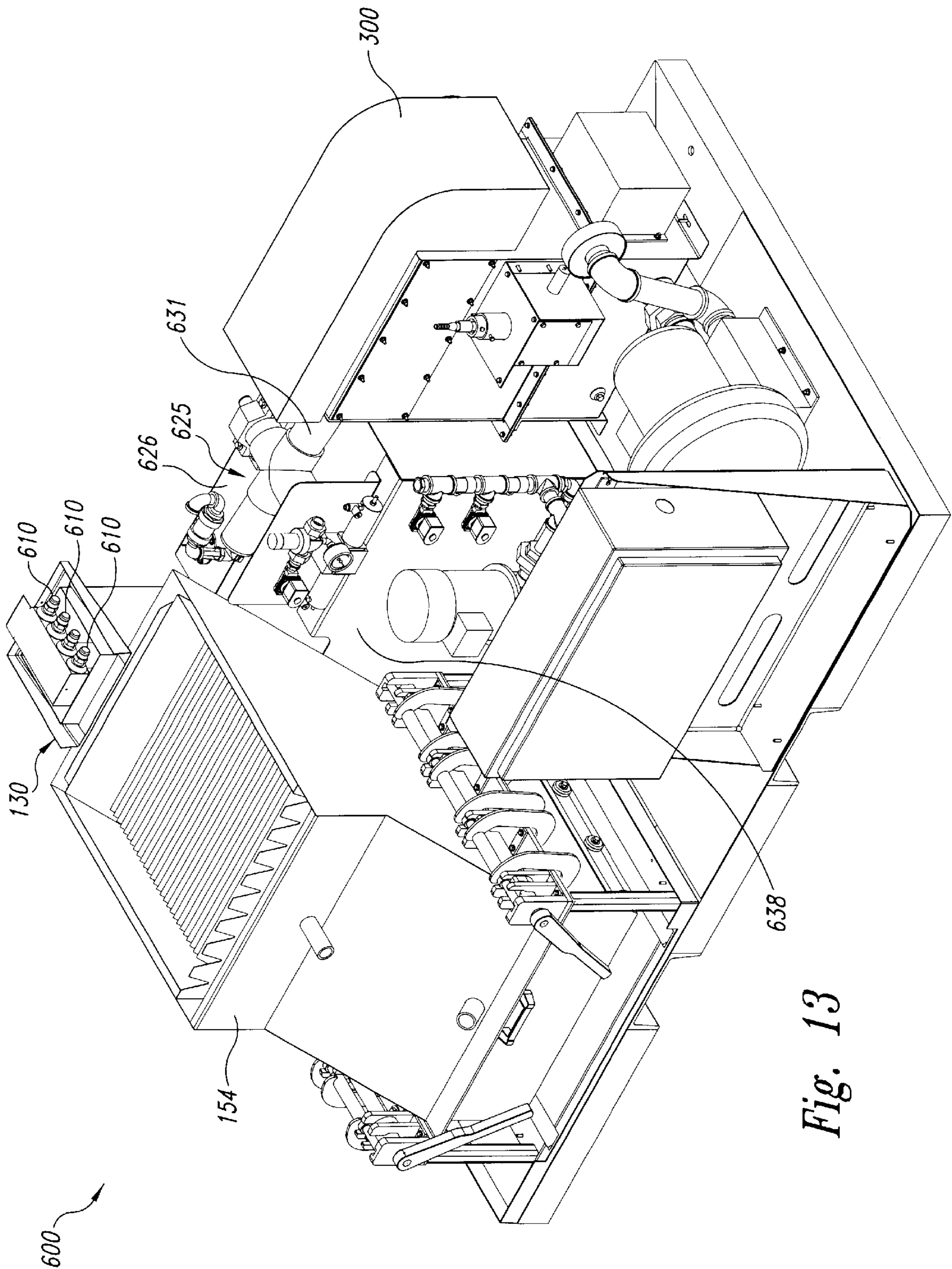


Fig. 13

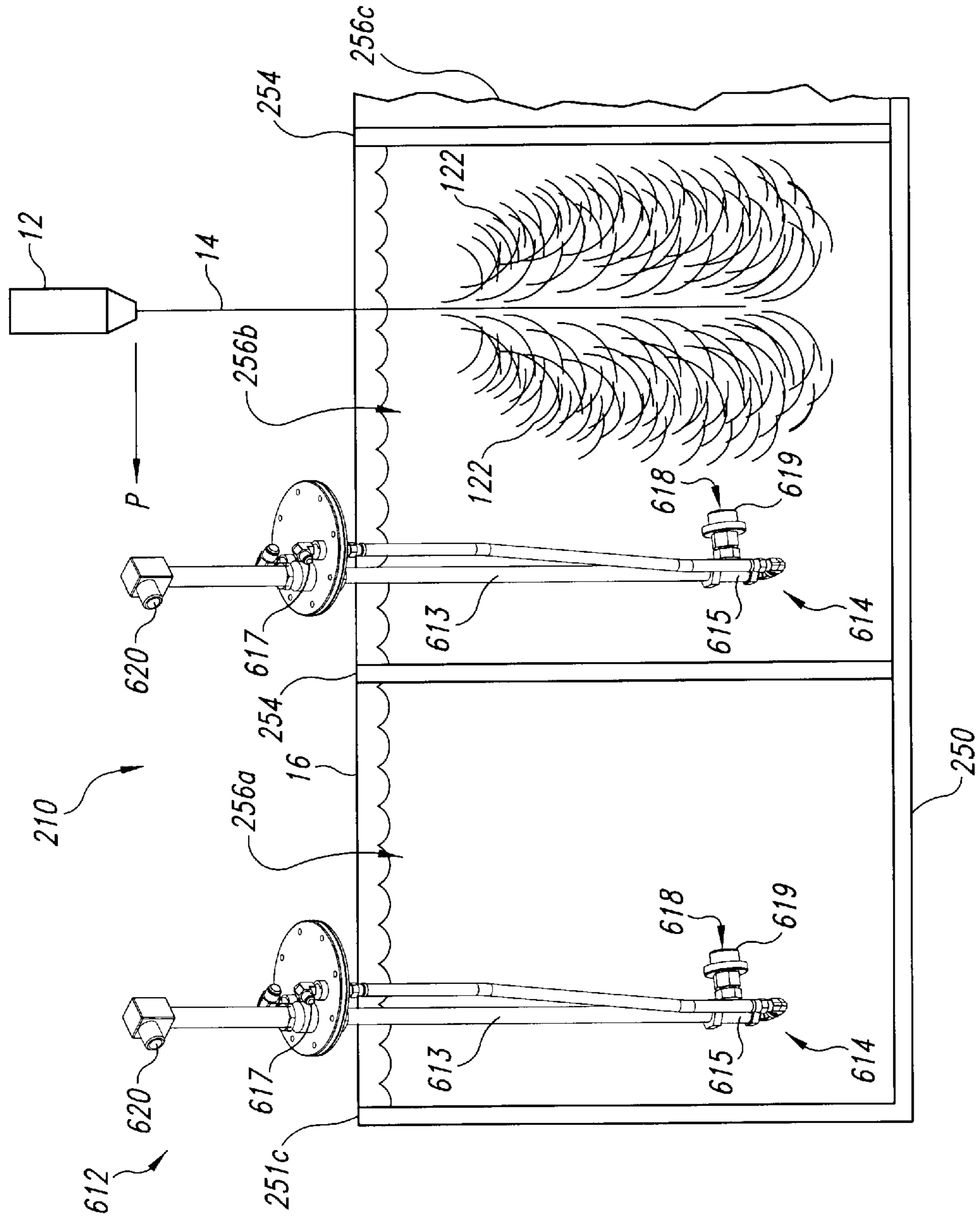


Fig. 14

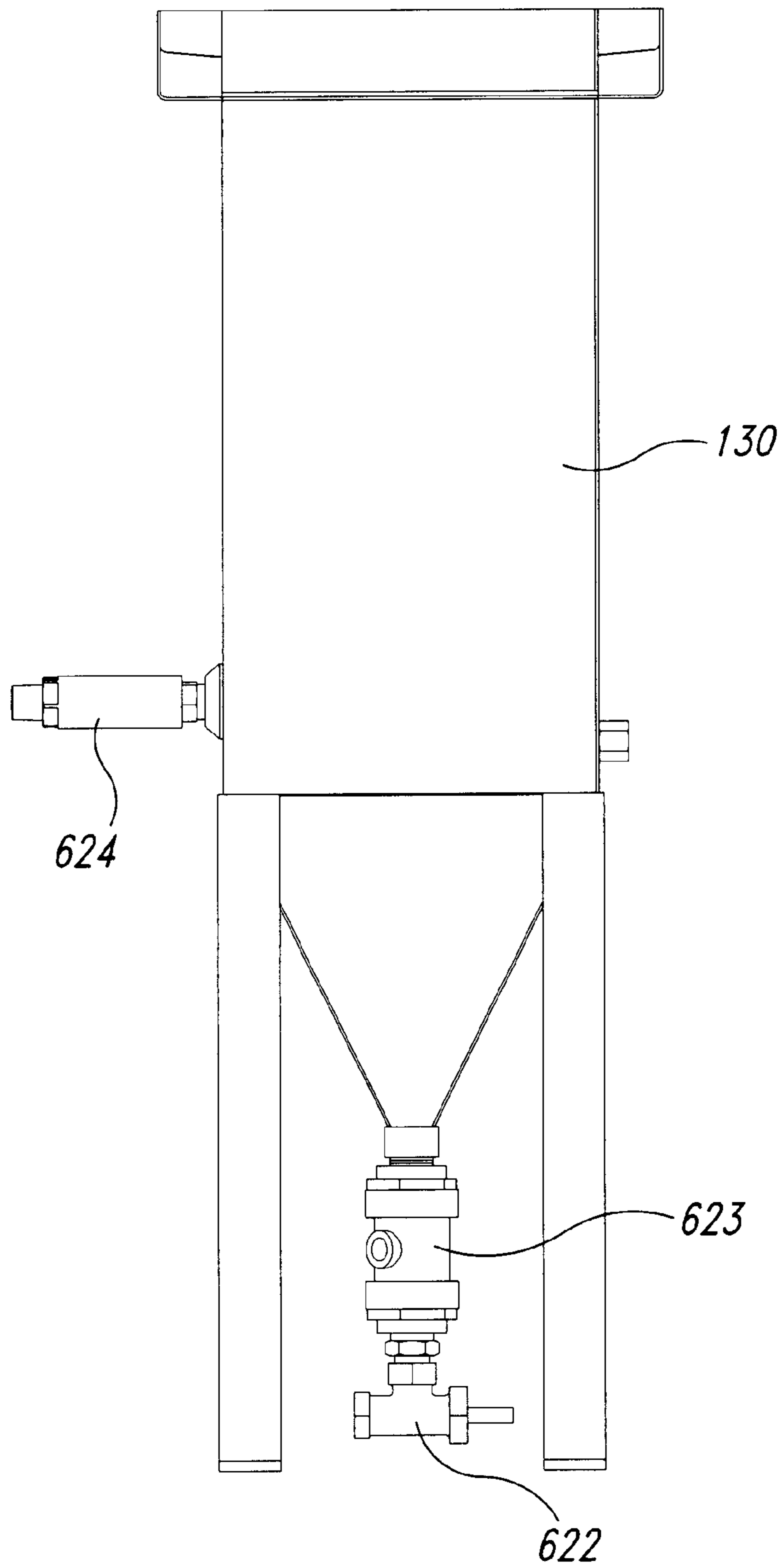


Fig. 15

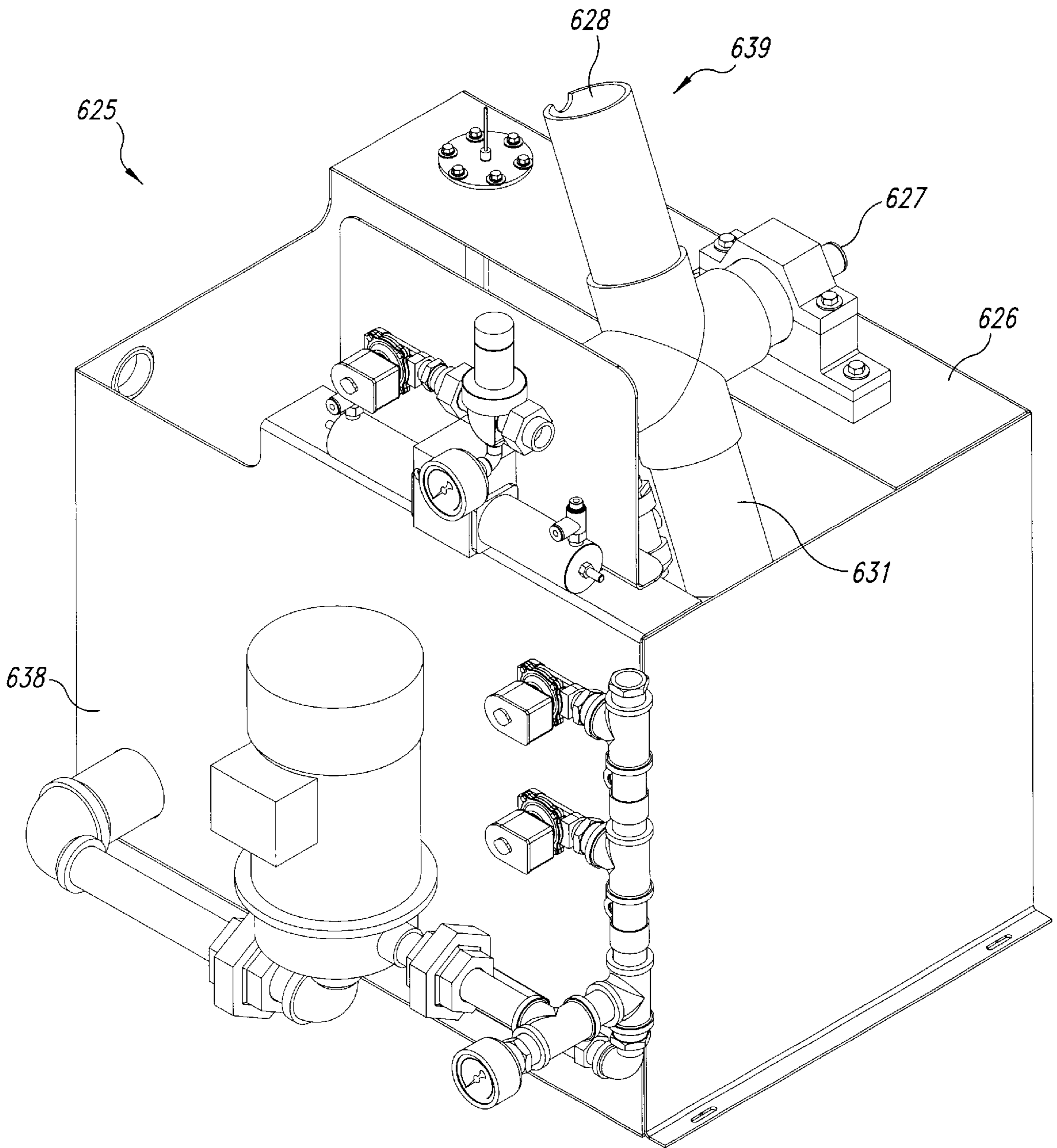


Fig. 16

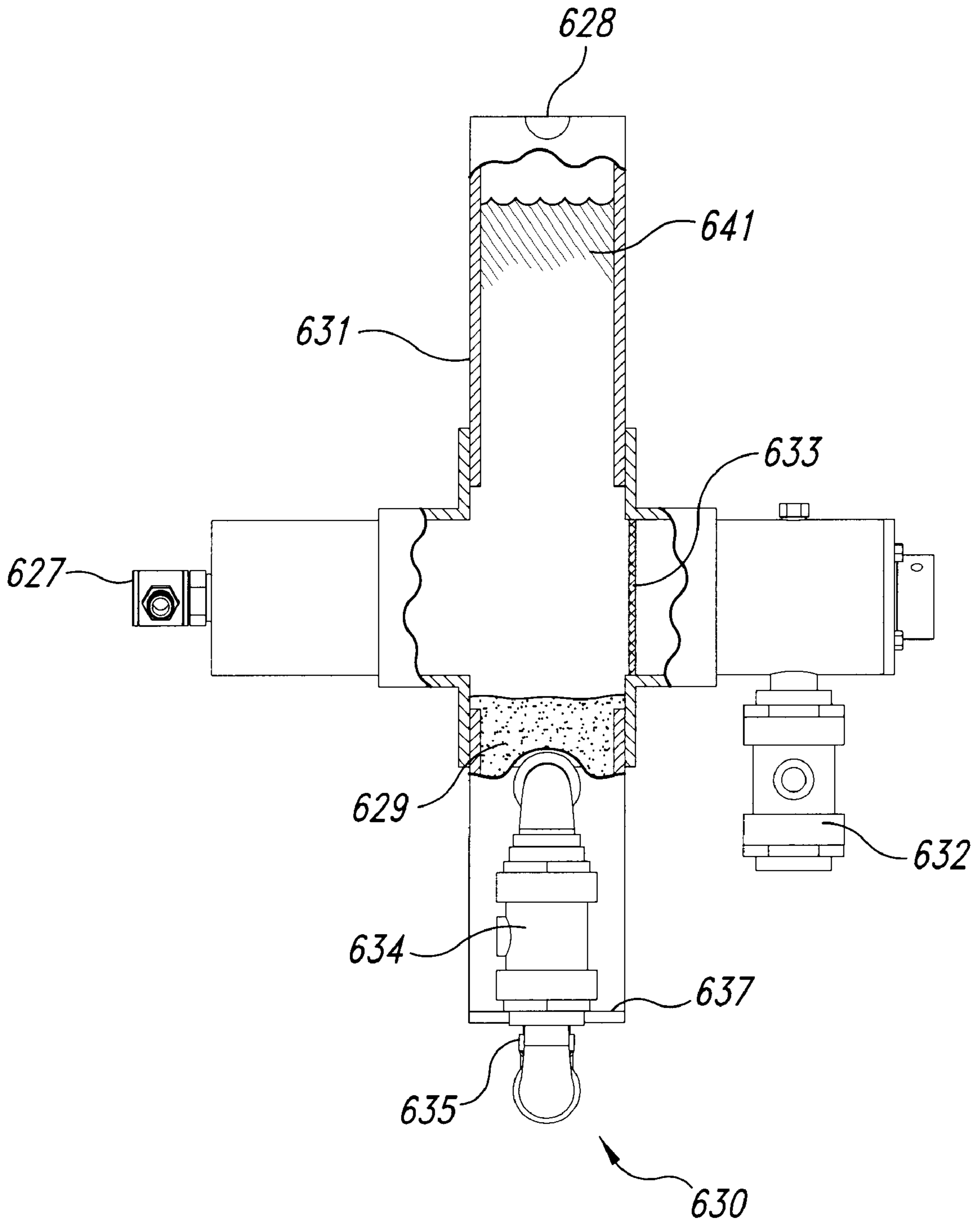


Fig. 17

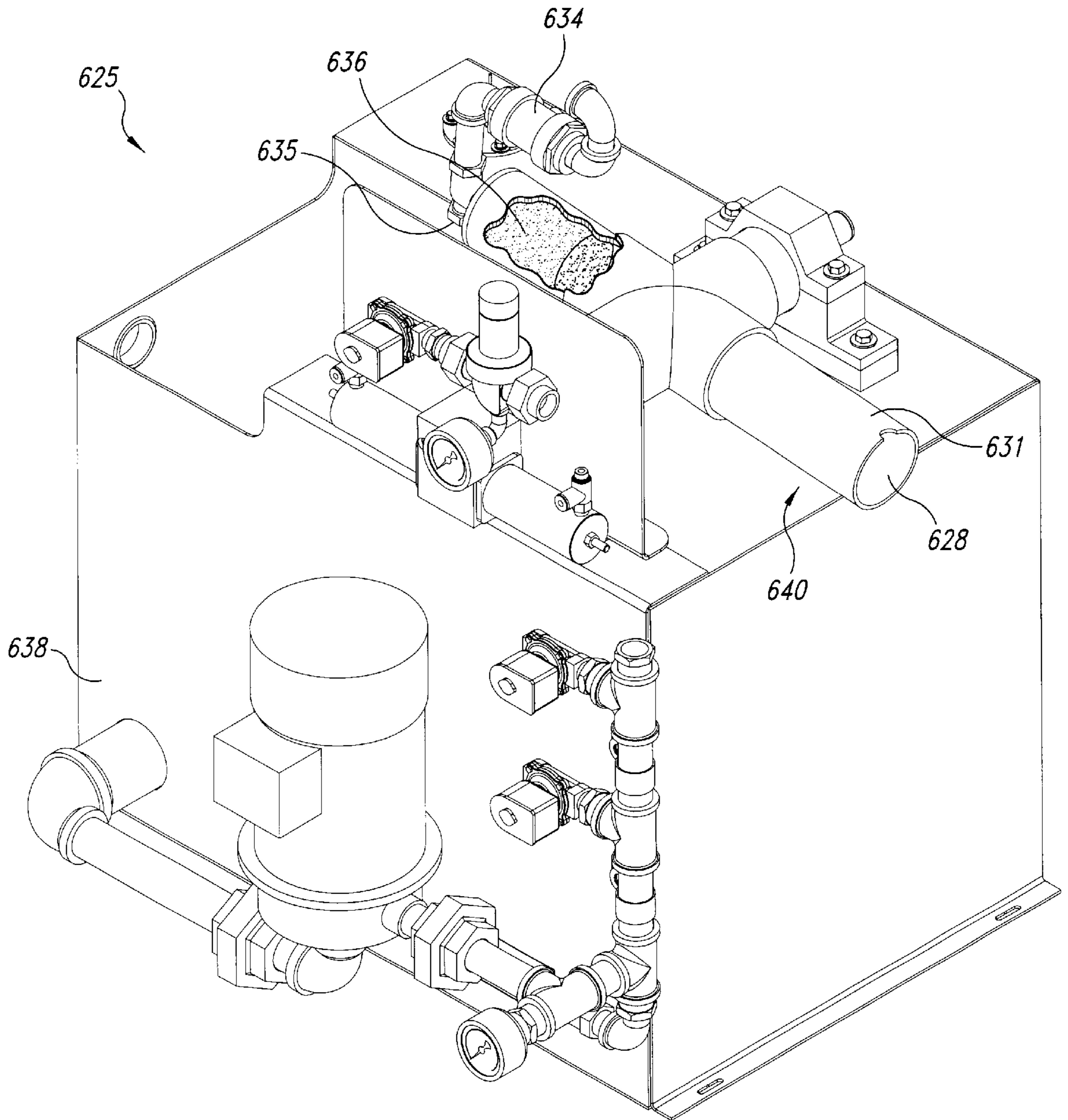


Fig. 18

APPARATUS AND METHODS FOR RECOVERING ABRASIVE FROM AN ABRASIVE-LADEN FLUID

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of U.S. patent application Ser. No. 09/383,044, filed Aug. 25, 1999 now pending, which is a continuation-in-part of U.S. patent application Ser. No. 09/069,223, filed Apr. 28, 1998, now pending.

TECHNICAL FIELD

This invention relates to apparatus and methods for recovering abrasive from an abrasive-laden fluid for use with abrasive jet cutting systems.

BACKGROUND OF THE INVENTION

Abrasive-jet cutting systems are used for cutting a wide variety of materials and for the production of a wide variety of products. In a typical abrasive-jet cutting system, abrasive particles are mixed with an ultra-high pressure fluid (e.g., water), and the resulting ultra-high pressure abrasive fluid is flowed through a cutting nozzle which directs an abrasive cutting jet onto a workpiece. The cutting nozzle may then be controllably moved across the workpiece to cut the workpiece into the desired shape. After the ultra-high pressure abrasive jet passes through the workpiece, the energy of the abrasive jet is dissipated and the abrasive fluid is collected in a catcher tank for disposal. Abrasive-jet cutting systems of this type are shown and described, for example, in U.S. Pat. No. 5,643,058 issued to Erichsen et al. and assigned to Flow International Corp. of Kent, Washington, which patent is incorporated herein by reference, corresponding to Flow's Bengal 4x4 and Paser 3 abrasive-jet cutting systems.

One abrasive material commonly used in abrasive-jet cutting systems is garnet. Garnet is well known for its hardness, resiliency, and overall performance in abrasive-jet cutting systems for a wide variety of workpiece materials. The cost of garnet, however, is not insubstantial. In existing abrasive-jet cutting systems, the consumable garnet particles represent 60 to 75 percent of the operating costs of the system. Research into the recovery and recycling of garnet particles indicates, however, that between 40 and 60 percent of the garnet particles are typically large enough to be recovered and recycled after initial use depending upon the material properties of the workpiece being cut. This fact makes abrasive recycling commercially viable.

Currently, abrasive recovery apparatus for use with abrasive-jet cutting systems may be divided into two broad categories. In a first category, the abrasive-laden fluid contained within the jet catcher of the abrasive jet cutting system is simply removed to a heater and subjected to heat to evaporate the fluid, leaving a mixture of abrasive particles and cuttings (or "fines") from the workpiece. This mixture of abrasive particles and cuttings is then sifted, such as through a system of successive screens, to remove the desirable abrasive particles from the undesirable cuttings and unusable particles.

In a second category, the abrasive-laden fluid is removed from the jet catcher and is separated by a wet separation process known as "classification" into a low-concentration abrasive flow and a wet recovered abrasive. The wet recovered abrasive is then heated to evaporate the fluid, leaving a mixture of dry recovered abrasive and cuttings for segrega-

tion. The low-concentration abrasive flow may simply be disposed of, or may be transported to a fine-separation tank to allow the fine particulates to settle and be recovered. In this second category of abrasive recovery systems, energy savings may be achieved because the low-concentration abrasive flow is not heated, with correspondingly lower operational costs. An abrasive recycling system of this type is shown and described, for example, in DE 19645142 issued to Hering et al. and assigned to Intrec Ges Innovative Technologien MbH of Berlin, Germany, which patent is incorporated herein by reference.

FIG. 1 is a schematic view of an existing abrasive recovery apparatus 10 of the type that uses classification. First, an abrasive-laden fluid 22 is pumped through the cutting head 12 to form an abrasive jet 14. The abrasive jet 14 is passed through a workpiece and collected in a catcher tank 16. A pump 18 draws the abrasive-laden fluid 22 from the catcher tank 16 and pumps it through a bypass 20 to a hydro-classifier 34.

The abrasive-laden fluid 22 enters into an upper portion 36 of a hydro-classifier 34. A clear-fluid pump 38 draws a clarified fluid 30 from a reserve tank 32 and pumps it into a lower portion 40 of the hydro-classifier 34. The abrasive-laden fluid 22 passes downwardly through a middle portion 42 of the hydro-classifier 34, while the clarified fluid 30 passes upwardly through the middle portion 42. The resulting mixing in the middle portion 42 of the hydro-classifier 34 causes the abrasive-laden fluid 22 to separate into a recovered abrasive 44 and a fine-particle flow 46. The recovered abrasive 44 collects in the bottom portion 40 of the hydro-classifier 34. The fine-particle flow 46 is routed to a clearing tank 26 for separation as described below.

The recovered abrasive 44 exits from the hydro-classifier 34 to a wet abrasive storage receptacle 47. If the wet abrasive storage receptacle 47 becomes filled to capacity, the bypass 20 directs the abrasive-laden fluid 22 directly to the clearing tank 26. An auger 48 transports the recovered abrasive 44 from the wet abrasive storage receptacle 47 to a dryer 50. In the dryer 50, the recovered abrasive 44 is heated to remove any remaining moisture, and is shaken and sifted through screens to separate the recovered abrasive 44 from any non-reusable particulates. The recovered abrasive 44 is then deposited into a collection tank 52 for reuse in the abrasive jet cutting system.

The fine-particle flow 46 is shunted to the clearing tank 26 where the particles are permitted to settle to the bottom. A sediment 27 which collects at the bottom of the clearing tank 26 includes cuttings from the workpiece as well as fine, non-reusable abrasive particulates. The sediment 27 is collected in a receptacle 28 for disposal or subsequent processing. Clarified fluid 30 exits from the settling tank 26 and is collected in the reserve tank 31. From the reserve tank 31, the clarified fluid 30 may be pumped by a filter pump 32 through a filter 33 and into a waste disposal system (not shown). Alternately, the clarified fluid 30 may be pumped by a return pump 35 from the reserve tank 31 back to the catcher tank 16 as necessary.

Although desirable results may be achieved using the abrasive recovery apparatus 10, certain characteristics may be improved. For example, the energy costs associated with the dryer 50 remain high and the throughput of the dryer 50 is low. Furthermore, the hydro-classifier 34 is typically extremely large. These characteristics tend to make the abrasive recovery apparatus 10 economically non-viable and it is impractical for most cutting environments.

SUMMARY OF THE INVENTION

This invention relates to apparatus and methods for recovering abrasive from an abrasive-laden fluid for use with

abrasive jet cutting systems. In one aspect, an apparatus in accordance with the invention includes an abrasive-laden fluid handling device coupled to a catcher tank of an abrasive jet cutting system, a pre-classifier fluidly coupled to the abrasive-laden fluid handling device, a hydro-classifier fluidly coupled to the pre-classifier, a fine-particle separation tank fluidly coupled to a clarified-fluid flow outlet of the hydro-classifier, a wet abrasive receptacle positioned to receive a wet recovered abrasive discharged from the hydro-classifier, a de-watering device engageable with the wet recovered abrasive in wet abrasive receptacle, and a dryer unit.

In operation, the abrasive-laden fluid handling device provides an abrasive-laden fluid from the catcher tank without requiring mechanical agitators. The pre-classifier separates the abrasive-laden fluid into a high concentration abrasive flow that enters the hydro-classifier, and a low concentration abrasive flow that is shunted back to the catcher tank, advantageously allowing a smaller, more economical and practical hydro-classifier to be used. Further, the de-watering device removes a residual, interstitial fluid content from the wet recovered abrasive, thereby reducing the energy costs associated with drying the recovered abrasive.

In a further aspect, the abrasive-laden fluid handling device includes an abrasive-laden fluid conduit having a first end in fluid communication with the catcher tank and an abrasive-laden fluid outlet positioned outside of the catcher tank. The abrasive-laden fluid handling device may include a fluid drive system coupled to the abrasive-laden fluid conduit, the fluid drive system driving abrasive-laden fluid contained within the catcher tank through the abrasive-laden fluid conduit. Alternately, the abrasive-laden fluid handling device may include a backflush valve that may be actuated to drive the abrasive-laden fluid back into the catcher tank, thereby flushing an abrasive buildup from the intake of the abrasive-laden fluid conduit. In a further aspect, the fluid drive system includes a pressurized gas source attached to the abrasive-laden fluid conduit.

In another aspect, an abrasive recovery apparatus includes a de-watering device including a housing having a wet abrasive intake and a de-watered abrasive outlet spaced apart from the wet abrasive intake. The housing is coupled to an eduction system that selectively draws air through the wet recovered abrasive to remove interstitial moisture from the wet abrasive, resulting in de-watered abrasive. In a first preferred embodiment, the housing includes an eductor port situated along an abrasive travel path extending between the wet abrasive intake and the de-watered abrasive outlet, an eductor inlet coupled to the eductor port and coupleable to a source of eduction air, and a transport device that transports the wet recovered abrasive along the abrasive travel path. In yet another aspect, the housing comprises a cylindrical housing and the transport device comprises an auger rotatably disposed within the cylindrical housing. In a further aspect, the apparatus includes an airflow control valve fluidly coupled to the eductor port. The airflow control valve may be positionable in a first position to draw an entrained airflow from within the housing through the eductor port, and a second position to backflow the eduction air through the eductor port into the housing.

In an alternative preferred embodiment, wet abrasive is selectively provided to a collection tube of a de-watering device, in response to pressures in the hydro-classifier, such pressures being measured by a pressure transducer coupled to the hydro-classifier. Flow to the collection tube of the de-watering device is selectively permitted and stopped by

selectively opening and closing a valve positioned at a bottom region of the hydro-classifier and selectively activating and deactivating a fluid eductor coupled to the hydro-classifier adjacent the valve. Once a selected amount of wet abrasive is allowed to flow into the collection tube of the de-watering device, the flow of wet abrasive is stopped, and a valve coupled to the housing is opened to decant fluid from the wet abrasive. An eductor coupled to the housing is activated to draw air through the wet abrasive, to further de-water the abrasive, resulting in the generation of a slug of de-watered abrasive. Once the de-watering is complete, the collection tube is rotated from a substantially vertical position to a substantially horizontal position, and the slug of de-watered abrasive is ejected via pressurized air to the dryer. The collection tube is then rotated to a substantially vertical position to once again receive a selected quantity of wet abrasive.

In yet another aspect, a vacuum transport device includes a dried abrasive receptacle, a vacuum pickup having a first end coupleable to a source of vacuum and a second end at least partially disposed within the dried abrasive receptacle and engageable with a volume of dried abrasive therein, and a standoff housing at least partially disposed about the vacuum pickup and at least partially engageable into the volume of dried abrasive, the standoff housing being positioned relative to the vacuum pickup to maintain a standoff distance between the vacuum pickup and a repose surface of the dried abrasive. The standoff housing maintains the standoff distance between the vacuum pickup and the repose surface to prevent clogging and ensure operation of the vacuum transport device.

In still another aspect, an abrasive recovery apparatus includes a pre-classifier having an abrasive-laden fluid inlet fluidly coupled to an abrasive-laden fluid flow, the pre-classifier separating the abrasive-laden fluid flow into a low-concentration abrasive flow and a high-concentration abrasive flow, and having a low-concentration flow outlet and a high-concentration flow outlet. The pre-classifier may include a turning plate that centrifugally separates the low-concentration flow from the high-concentration flow.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic view of an abrasive recovery apparatus for an abrasive jet cutting system in accordance with the prior art.

FIG. 2 is an isometric view of an abrasive recovery apparatus for an abrasive jet cutting system in accordance with an embodiment of the present invention.

FIG. 3 is a schematic view of the abrasive recovery apparatus of FIG. 2.

FIG. 4 is a partially-sectional isometric view of an embodiment of an abrasive-laden fluid collection device of the abrasive recovery apparatus of FIG. 2.

FIG. 5 is a partially-sectional isometric view of embodiment of a hydro-classifier of the abrasive recovery apparatus of FIG. 2.

FIG. 6 is a partially-sectional isometric view of an embodiment of a fine-particle separation tank of the abrasive recovery apparatus of FIG. 2.

FIG. 7 is a partially-sectioned isometric view of an embodiment of a de-watering device of the abrasive recovery apparatus of FIG. 2.

FIG. 8 is an enlarged partial cross-sectional view of the air eduction device of FIG. 7.

FIG. 9 is an enlarged partial cross-sectional view of the air eduction device of FIG. 7.

FIG. 10 is an isometric view of a dryer unit of the abrasive recovery apparatus of FIG. 2.

FIG. 11 is a partially-sectional isometric view of an embodiment of a vacuum transport device of the abrasive recovery apparatus of FIG. 2.

FIG. 12 is a flowchart representation of an embodiment of a process for operating the abrasive recovery apparatus of FIG. 2.

FIG. 13 is an isometric view of an abrasive recovery apparatus provided in accordance with an alternative embodiment of the present invention.

FIG. 14 is a partial cross-sectional view of an abrasive-laden fluid collection device forming a portion of the abrasive recovery apparatus of FIG. 13.

FIG. 15 is a front elevational view of a hydro-classifier of the abrasive recovery apparatus of FIG. 13.

FIG. 16 is an isometric view of a de-watering device of the abrasive recovery apparatus of FIG. 13, with a collection tube shown in a first position.

FIG. 17 is a partial cross-sectional elevational view of a sub-assembly of the de-watering device of FIG. 16.

FIG. 18 is an isometric view of a de-watering device of the abrasive recovery apparatus of FIG. 13, with a collection tube shown in a second position.

DETAILED DESCRIPTION OF THE INVENTION

The present disclosure is directed toward apparatus and methods for recovering abrasive from an abrasive-laden fluid for use with abrasive jet cutting systems. Specific details of certain embodiments of the invention are set forth in the following description, and in FIGS. 2–18, to provide a thorough understanding of such embodiments. A person of ordinary skill in the art, however, will understand that the present invention may have additional embodiments, and that the invention may be practiced without several of the details described in the following description.

FIG. 2 is an isometric view of an abrasive recovery apparatus 100 for use with an abrasive jet cutting system in accordance with the present invention. FIG. 3 is a schematic view of the abrasive recovery apparatus 100 of FIG. 2 in operation with a catcher tank 16 and cutting head 12 of an abrasive jet cutting system. In this embodiment, the abrasive recovery apparatus 100 includes an abrasive-laden fluid handler 210 that continuously removes abrasive-laden fluids from the catcher tank 16 without using mechanical agitators to suspend the abrasive particles in the waste fluid. The abrasive recovery apparatus 100 also includes a pre-classifier 120 that improves the quality and limits the amount of abrasive-laden flow entering a hydro-classifier 130. Finally, the apparatus 100 includes a de-watering device 170 that removes fluid from a wet recovered abrasive prior to entering a dryer, improving the drying process and the economic feasibility of the system.

FIG. 4 is a cross-sectional side elevational view of an embodiment of the abrasive-laden fluid handler 210 of FIG. 2. The abrasive-laden fluid handler 210 is fully shown and described in co-pending U.S. patent application Ser. No. 09/069,223, incorporated herein by reference.

Referring to FIGS. 2–4, the catcher tank 16 includes a bottom panel 250, first and second side-walls 251a and 251b projecting upward from opposing sides of the bottom panel 250, and first and second end-walls 251c and 251d projecting upward from opposing ends of the bottom panel 250. The first and second side-walls 251a and 251b are attached

to the first and second end-walls 251c and 251d to form a large cavity. The catcher tank 16 also includes a central divider 252 (see FIG. 2) extending longitudinally within the tank 16, and a plurality of crossing dividers 254 extending transverse to the central divider 252. The dividers 252 and 254 define a plurality of compartments 256 (identified by reference numbers 256a–256c) in the catcher tank 16. One commercially-available catcher tank 16 suitable for this purpose is the catcher tank of the Bengal 4×4 abrasive-jet cutting system available from Flow International Corp. of Kent, Wash.

The compartments 256 receive the abrasive-laden fluid 14 from the cutting head 12 as the cutting head 12 is traversed along a cutting path P. Additionally, each compartment 256 is configured to control the abrasive-laden fluid 122 within the tank 16. For example, when the abrasive jet 14 is aligned with compartment 256b, the dividers 252 and 254 defining this compartment control the fluid flow such that the abrasive jet 14 alone suspends a significant portion of the abrasive particles in the abrasive-laden fluid 122. As such, by dividing the tank 16 into smaller compartments 256, the abrasive jet 14 maintains at least a substantial portion of the abrasive particles in suspension in the abrasive-laden fluid 122 within a particular compartment aligned with the abrasive jet 14 without additional mechanical agitation. Typically, each compartment is approximately between 1'×1' and 4'×8', and more preferably about 2'×4'. As explained in more detail below, the abrasive-laden fluid handler 210 continuously removes abrasive-laden fluid 122 and abrasive particles from the compartments 256.

As shown in FIG. 4, the abrasive-laden fluid handler 210 includes a number of conduit sections 260 (identified by reference numbers 260a and 260b). The conduit sections 260 are configured to transport abrasive-laden fluid 122 from the compartments 256a, 256b and 256c. The conduit sections 260 include at least a first conduit section 260a having a first end 262 positioned in the lower portion of compartment 256b and a second end 264 positioned in compartment 256a. The first conduit section 260a also has a first intake opening 266 proximate to the bottom panel 250, a second intake opening 268 located to receive a fluid flow from a conduit section from the adjacent upstream compartment 256c, and a vent 267 toward the second end 264. The second intake opening 268, for example, can be a funnel. The conduit sections 260 can also include a second conduit section 260b similar to the first conduit section 260a, and thus like reference numbers refer to like components. The second conduit section 260b has a first end 262 positioned in the lower portion of compartment 256a and a second end 264 coupled to a trough 117. The second intake opening 268 of the second conduit section 260b is located to receive a first fluid flow F_1 from the second end 264 of the first conduit section 260a in a so-called “cascade” arrangement. Accordingly, the first and second conduit sections 260a and 260b define a conduit that transports the abrasive-laden fluid 122 from the compartments 256a and 256b to the trough 117.

To generate fluid flows through the conduit sections 260, a fluid drive system 270 is preferably coupled to the conduit sections 260 to drive the abrasive-laden fluid 122 through the conduit sections 260. In this particular embodiment, the fluid drive system 270 includes a fluid driver 271, a primary line 272 coupled to the fluid driver 271, and a plurality of branch feed lines 274 coupled to the primary line 272. The fluid driver 271 can be a pressurized gas source, such as an air compressor. The primary line 272 generally passes through the dividers 252 and 254 to supply pressurized gas

to all of the compartments 256. The branch feed lines 274 are attached to the conduit sections 260 below the fluid level of the abrasive-laden fluid 122 in the compartments 256.

In operation, the pressurized gas source 271 injects a compressed gas 278, such as air, into the conduit sections 260. The compressed gas 278 is metered into the bottom of each conduit section 270. The gas 278 accordingly rises through the vertical portions of the conduit sections 260, creating a pumping action that draws abrasive-laden fluid 122 through the conduit sections 260. The gas 278 passes through the vents 267, while the fluid 122 continues to flow through the conduit sections 260. The second conduit section 260b includes a backflush valve 113 which may be used to selectively control the flow of the abrasive-laden fluid 122 out of the catcher tank 16. The fluid drive mechanism 270, therefore, generates the first fluid flow F_1 through the first conduit section 260a and a second fluid flow F_2 through the second conduit section 260b and into the trough 117. Typically, each conduit section 260 consumes approximately 3 to 5 SCFM and generates approximately 10 GPM of abrasive-laden fluid flow through the conduit section 260.

The abrasive-laden fluid handler 210 removes abrasive-laden fluid 122 from at least one of the compartments 256 as the abrasive jet 14 moves along the cutting path P. As the abrasive jet 14 passes over the compartment 256b, the abrasive jet 14 agitates the abrasive-laden fluid 122 to suspend a significant portion of abrasive particles within the compartment 256b without additional mechanical agitation. The compartment 256b is properly sized to permit the abrasive jet 14 to adequately suspend abrasive particles (and fines) in the abrasive-laden fluid 122 without additional mechanical agitation because the dividers 252 and 254 concentrate the turbulence generated by the abrasive jet 14 and contain the abrasive particles within the relatively small volume of compartment 256b. The fluid flow F_1 through the first conduit section 260a accordingly draws a portion of the abrasive-laden fluid 122 and the suspended abrasive particles through the first conduit section 260a. The first fluid flow F_1 exits from the first conduit section 260a, and the second fluid flow F_2 in the second conduit section 260a draws the first fluid flow F_1 into the second intake opening 268 of the second conduit section 260b. The abrasive-laden fluid 122 from compartment 256b is thus transported to the trough 117 through the first and second conduit sections 260a and 260b.

Occasionally, a buildup of abrasive will develop in the catcher tank 16 around the intake openings 266 of the conduit sections 260, obstructing the intake openings 266 and hampering the flow of abrasive-laden fluid into the conduit sections 260. If enough abrasive buildup occurs, the air bubbles from the fluid drive system 270 will not be able to unplug the intake openings 266. To remedy this problem, the backflush valve 113 (shown in FIG. 4 as a "pinch" valve) may be periodically closed to force air through the conduit sections 260 and out the intake openings 266, flushing out any buildup of abrasive in the intake region and preventing clogging. The backflushing operation may be automatically controlled by coupling the backflush valve 113 to a control system and a timer.

The abrasive-laden fluid handler 210 advantageously removes the abrasive from the catcher tank 16 without the need for periodic shoveling of the catcher tank 16. In this way, the costs associated with the labor-intensive task of removing the abrasive from the tank and the downtime of the abrasive-jet cutting system are avoided. Another advantage is that the abrasive-laden fluid handler 210 provides a continuous flow of abrasive-laden fluid to the remaining components of the abrasive recovery apparatus 100.

As best shown in FIG. 2, the abrasive-laden fluid 122 flows through the trough 117 and enters the pre-classifier 120. The pre-classifier 120 includes a turning plate 121 that causes the flow of abrasive-laden fluid 122 to be turned. In the embodiment shown in FIG. 2, the turning plate is positioned at an approximately 45 degree angle to the initial flow direction of the abrasive-laden fluid 122. The pre-classifier 120 also includes a low-concentration abrasive flow outlet 126 and a high-concentration abrasive outlet 128.

In operation, the abrasive-laden flow 122 enters the pre-classifier 120 and is turned by the turning plate 121, subjecting the abrasive-laden flow 122 to a centrifugal force. As the abrasive-laden flow 122 turns around the end of the turning plate 121, it is accelerated, thereby using the centrifugal force to separate the abrasive-laden flow 122 into a low-concentration abrasive flow 123 and a high-concentration abrasive flow 124. The high-concentration abrasive flow 124 flows out of the high-concentration abrasive flow outlet 128 and into a hydro-classifier 130, as described more fully below. The low-concentration abrasive flow 123 exits from the pre-classifier 120 through the low-concentration abrasive flow outlet 126 and back into the catcher tank 16.

FIG. 5 is a partially-sectional isometric view of an embodiment of the hydro-classifier 130 of the abrasive recovery apparatus 100 of FIG. 2. The hydro-classifier 130 includes an open top 132 through which the high-concentration abrasive fluid 124 enters an upper portion 134 of the hydro-classifier 130. A teeter fluid inlet 138 is disposed within a middle portion 142 of the hydro-classifier 130 and is coupled to a source of teeter (or "clarified") fluid 136. A manifold 140 distributes the teeter fluid 136 into the middle portion 142 of the hydro-classifier 130. The teeter fluid 136 rises upwardly through the middle portion 142 and mixes with the high-concentration abrasive fluid 124 flowing downwardly from the upper portion 134.

The mixing of the teeter fluid 136 with the high-concentration abrasive fluid 124 separates a recovered abrasive 144 from a fine particle flow 147. The fine-particle flow 147 exits from the upper portion of 134 of the hydro-classifier 130 via a fine-particle flow outlet 149. As shown in FIG. 5, the recovered abrasive 144 collects in a lower portion 146 of the hydro-classifier 130. The lower portion 146 includes a recovered abrasive outlet 148. A wet abrasive control valve 150 is coupled to the recovered abrasive outlet 148 and is adjustably positionable between an open and a closed position. The wet abrasive control valve 150 may be any suitable type, including, for example, a pinch valve.

A pressure transducer 152 is disposed within the middle portion 142 of the hydro-classifier 130. The pressure transducer 152 senses a fluid pressure within the hydro-classifier 130. Based on the pressure measured by the pressure transducer 152, the level of recovered abrasive 144 in the lower portion 146 may be determined. Based on a measured pressure signal from the pressure transducer 152, the wet abrasive control valve 150 may be opened to release the recovered abrasive 144 from the hydro-classifier 130. Commercially-available hydro-classifiers suitable for this purpose include, for example, those available from Carpc, Inc. of Jacksonville, Fla.

The pre-classifier 120 advantageously improves the abrasive concentration of the fluid entering the hydro-classifier 130. Because the low-concentration abrasive flow 123 is separated from the high-concentration abrasive flow 124 by the centrifugal force and is re-directed back into the catcher tank 16, the volume of fluid entering the hydro-classifier 130

is reduced, and the concentration of abrasive within the fluid entering the hydro-classifier **130** is increased. Because the size and efficiency of the hydro-classifier **130** is driven by the concentration of the abrasive-containing fluid entering the hydro-classifier **130**, the pre-classifier **120** advantageously permits a smaller, more economically feasible hydro-classifier **130** to be used. Thus, the pre-classifier **120** improves the economic feasibility of the abrasive recovery apparatus **100** and enables the apparatus to be employed more practically in a wide variety of environments.

Similarly, the abrasive-laden fluid handler **210** advantageously improves the abrasive concentration of the fluid entering the hydro-classifier **130**. The abrasive-laden fluid handler **210** captures the abrasive-laden fluid **122** that contains a higher concentration of abrasive than the previous method of simply pumping fluid from the catcher tank **16**. The abrasive-laden fluid handler **210** captures the abrasive-laden fluid **122** from the compartments **256** into which the abrasive jet **14** enters the catcher tank **16**, thus enabling a higher concentration abrasive-laden fluid **122** to be captured and removed from the catcher tank **16**. In turn, the higher concentration of abrasive-laden fluid **122** entering the hydro-classifier **130** advantageously permits a smaller, more economically feasible hydro-classifier **130** to be used. Thus, the abrasive-laden fluid handler **210** improves the economic feasibility and practicality of the abrasive recovery apparatus **100**.

FIG. 6 is a partially-sectional isometric view of an embodiment of a fine-particle separation device **154** of the abrasive recovery apparatus **100** of FIG. 2. The particle separation device **154** includes a settling tank **156** having a fine-particle flow inlet **158** and a clarified fluid outlet **160**. A plurality of baffles **162** are positioned within the settling tank **156** between the fine-particle flow inlet **158** and the clarified fluid outlet **160**. The baffles **162** slow the speed of the flow entering the settling tank **156** and provide additional surface area for the accumulation of fine particles. A collection trough **164** is disposed within the settling tank **156**, traversing the settling tank **156** through cutouts in the baffles **162** and projecting out of the clarified fluid outlet **160**.

In operation, the fine-particle flow **147** enters the settling tank **156** through the fine-particle flow inlet **158**. The fine-particle flow **147** encounters the baffles **162** which slow the flow and inhibit turbulence within the settling tank **156**. Into relatively stagnant settling tank **156**, the fine particle flow **147** separates into a clarified fluid **166** and a fine sediment **168**. The fine sediment **168** collects on the baffles **162** and eventually drops to the bottom of the settling tank **156** for subsequent removal and disposal. As the fluid level within a settling tank **156** increases, the clarified fluid **166** flows over the edges of and into the collection trough **164**, passing through the collection trough **164** and out the clarified fluid outlet **160**. The clarified fluid **160** may then be pre-circulated into the catcher tank **16** of the abrasive jet cutting system, or may be disposed of in an environmentally conscious manner. Suitable fine-particle separation of devices **154** include, for example, the wet separation gravity separators commercially-available from Outokumpu Technology, Inc. of Jacksonville, Fla.

FIG. 7 is a partially-sectional isometric view of an embodiment of a de-watering device **170** of the abrasive recovery apparatus **100** of FIG. 2. The de-watering device **170** includes a wet abrasive receptacle **172** that receives the recovered abrasive **144** from the wet abrasive outlet **148** of the hydro-classifier **130**, and a wet abrasive transport device **174** having a cylindrical housing **176** that surrounds an auger **178**. The auger **178** transports the wet recovered

abrasive **144** through the cylindrical housing **178** past first and second air eduction ports **182**, **184** to a de-watered abrasive outlet **186**. A variable speed motor **179** is coupled to the cylindrical housing **178** to drive the auger **178**. The recovered abrasive **144** exits from the de-watered abrasive outlet **186** to a dryer unit **300** (see FIG. 3).

The de-watering device **170** also includes an air eduction system **180** having first and second eduction air inlets **183**, **185** coupled to the first and second eductor ports **182**, **184**, respectively. First and second airflow valves **187**, **188** are also coupled to the first and second eductor ports **182**, **184**, respectively, to control a flow of air through the first and second eductor ports **182**, **184**.

FIG. 8 is an enlarged partial cross-sectional view of the air eduction system **180** of FIG. 7. As shown in FIG. 8, the first eductor port **182** fluidly communicates with an interior region **190** of the cylindrical housing **176** via a first conductor aperture **192**. Similarly, the second eductor port **184** fluidly communicates with the interior region **190** via a second eductor aperture **194**. Screens **196** cover the first and second eductor apertures **192**, **194** to prevent the outflow of the wet recovered abrasive **144** (not shown) out of the interior region **190**. The first and second eduction air inlets **183**, **185** are fluidly coupled to a source of high-pressure air by air supply lines **198**.

In a first mode of operation, the first and second airflow valves **187**, **188** are opened, and a high-pressure air F_1 from the air supply lines **198** enters the first and second eduction air inlets **183**, **185**. As the high-pressure air F_1 travels through the first and second air eductor ports **182**, **184**, a flow of entrained air F_2 is pulled by the high-pressure air F_1 into the interior region **190** of the cylindrical housing **176** through the dried-abrasive outlet **186**. The flow of entrained air F_2 is drawn by the high-pressure air F_1 through the wet recovered abrasive **144** (not shown) in the interior region **190** where it evaporates and collects moisture from the wet recovered abrasive **144**. A wet entrained airflow F_3 is then drawn through the screens **196** and into the first and second air eductor ports **182**, **184**. The wet entrained airflow F_3 mixes with the high-pressure air F_1 to form a wet exhaust flow F_4 that is blown out of the first and second airflow valves **187**, **188**.

Thus, in the first mode of operation shown in FIG. 8, the air eduction system **180** advantageously removes a residual, interstitial moisture content from the wet recovered abrasive **144**. As the auger **178** continuously pushes wet recovered abrasive **144** through the interior region **190** of the cylindrical housing **176**, the air eduction system **180** removes residual moisture from the recovered abrasive **144** to produce a de-watered abrasive **144A**. By lowering the water content of the de-watered abrasive **144A** prior to delivery to the dryer unit **300**, the amount of energy needed to dry the de-watered abrasive **144** is reduced. Consequently, the operational costs of the abrasive recovery apparatus **100** are reduced, making the abrasive recovery operation more economically feasible.

One may note that several of the features of the air eduction system **180** may be varied from the embodiment described above and shown in the accompanying figures. For example, one of the air eduction ports, air eduction inlets, and airflow control valves may be eliminated, or any number of air eduction ports may be added. Alternately, an air eduction supply port may be added within the cylindrical housing **176** so that the flow of entrained air F_2 enters through a separate air eduction supply port rather than through the de-watered abrasive outlet **186**. The auger may

be replaced by an equivalent transport device. Of course, the dimensions and specific design details of the air eduction system components may also be varied without deviating from the scope and spirit of the invention.

Although the dimensions of the air eduction system **180** may be varied to achieve acceptable results, experiments have shown that the effectiveness of the air eduction system **180** is effected by the size of the auger **178** and inside diameter of the cylindrical housing **176**. If the dimensions of the air eduction system **180** are held constant, reducing the diameter of the auger/cylindrical housing improves the de-watering effect of the air eduction system. For example, for an air eduction system **180** having first and second air eduction ports **182**, **184** each being 0.5 inches in diameter, and a de-watered abrasive outlet **186** that is 1.0 inches in diameter, and a high-pressure supply of air F_1 of approximately 60 psi, a 1 inch diameter auger/cylindrical housing (inside diameter) is preferred over an auger/cylindrical housing of larger diameter. Regardless of the actual dimensions and operating conditions, the air eduction system **180** preferably (but not necessarily) provides a de-watered abrasive **144A** having approximately 11 percent or less water content by weight.

FIG. 9 is an enlarged partial cross-sectional view of the air eduction system **180** of FIG. 7 in a second mode of operation. In this second mode, the first and second airflow valves **187**, **188** are closed, causing the high-pressure air F_1 to flow back through the first and second air eduction ports **182**, **184** and into the interior region **190** of the cylindrical housing **176**. The backflow F_4 of air passes through the screens **196** covering the first and second eductor apertures **192**, **194**, dislodging and clearing any of the wet recovered abrasive **144** from the screens **196**. The backflow F_4 of air then passes through the de-watered abrasive **144A** (not shown), and ejects a volume of the de-watered abrasive **144A** out of the interior region **190** through the de-watered abrasive outlet **186**. Thus, in the second mode of operation shown in FIG. 9, the air eduction system **180** blows a mixture of air and de-watered abrasive F_5 out the de-watered abrasive outlet **186**.

In the second mode of operation, the air eduction system **180** advantageously provides the backflow F_4 of air through the screens **196** to keep the screens unblocked. The backflow F_4 ensures that the screens remain unblocked so that in the first mode of operation the wet entrained airflow F_3 passes readily through the screens **196** to maximize the drying of the recovered abrasive **144**. By alternating between the first and second modes of operation, the wet recovered abrasive **144** may be de-watered and then the airflow through the air eduction apertures **192**, **194** reversed to unblock the screens **196**. For an air eduction system **180** having the dimensions and operating parameters described above, desirable results have been achieved by operating the system for approximately one-minute in the first mode of operation to de-water the recovered abrasive **144**, and then switching to the second mode of operation for approximately one second to unblock the screens **196**.

Another advantage is that in the second mode of operation, the air eduction system **180** blows the air and dried abrasive mixture F_5 out of the de-watered abrasive outlet **186** to help break up clumps of de-watered abrasive **144A**. It is known that large clumps of abrasive are more difficult to dry than smaller clumps or individual abrasive particles. When the air eduction system **180** is operated in the second mode of operation shown on FIG. 9, the pulse of air and dried abrasive mixture F_5 has the desirable effect of helping to break LIP clumps of the de-watered abrasive

144A exiting from the de-watered abrasive outlet **186**. Thus, the de-watered abrasive **144A** may be more efficiently dried by the dryer unit **300** as described more fully below.

It is understood that in an alternate embodiment, the air eduction system **180** may be modified to operate using a vacuum system. For example, in the first mode of operation, the first and second air eductor ports **182**, **184** may be coupled to the vacuum system so that the flow of entrained air F_2 is drawn into and through the interior region **190**, and the wet entrained airflow F_3 is drawn through the screens **196** and out through the first and second airflow valves **187**, **188**. In this embodiment, the high-pressure eduction air F_1 from the air supply lines **198** would be unnecessary in the first mode of operation. In the second mode of operation, however, the first and second airflow valves **187**, **188** would be closed to the vacuum system, and the high-pressure air F_1 from the air supply lines **198** would be used to generate the backflow F_4 of air through the screens **196**. Furthermore, because the eduction air acts similar to a source of vacuum by drawing the flow of entrained air F_2 into and through the interior region **190**, and the flow of wet entrained air F_3 out through the screens **196**, the use of the term "eductor" throughout this discussion may in most cases be interchanged with the term "vacuum."

In another alternate embodiment, a de-watering airflow may simply be blown through the wet recovered abrasive **144**. For example, the de-watered abrasive outlet **186** may open into a pressurizeable chamber **700** (shown in dashed lines in FIG. 8) coupled to a source of pressurized air **710** (e.g., a pump). With the pressurizeable chamber **700** pressurized, a de-watering airflow may flow from the pressurizeable chamber **700** through the interior region **190** and the wet recovered abrasive **144** and out of the housing **176**. The de-watering airflow may exit the housing **176** through, for example, the ports **182**, **184**, or may simply blow the de-watering airflow out of the open end of the housing at which the auger **178** picks up the wet recovered abrasive **144** from the wet abrasive receptacle **172**.

FIG. 10 is an isometric view of the dryer unit **300** of the abrasive recovery apparatus **100** of FIG. 2. The dryer unit **300** includes a containment tank **302** having a de-watered abrasive inlet **304** and a dried abrasive outlet **306**. A horizontal floor partition **320** separates the interior of the containment tank **302** into an upper drying chamber **310** and a lower heater chamber **330**. The floor partition **320** is porous and permits the flow of air from the lower heater chamber **330** to the upper drying chamber **310**. A plurality of path control walls **308** span the drying chamber **310** and divide the drying chamber **310** into a plurality of drying sections **309** (designated as **309A**, **309B**, and **309C** in FIG. 10). Each path control wall **308** includes an upper edge **312** having a notch **314** formed therein. A layer of drying abrasive **315** partially fills the drying chamber **310**. The layer of drying abrasive **315** may include a priming layer of abrasive, or may be formed by the de-watered abrasive **144A** entering the de-water abrasive inlet **304**.

A plurality of heater elements **332** are positioned within the lower heater chamber **330**. A heating air inlet **334** is disposed within a lower portion of de-containment tank **302** to allow a flow of heating air **336** to enter the lower heater chamber **330**. A blower **338** is coupled to the heating air inlet **334** by a blower duct **340**. An exhaust port **316** projects from an upper surface **318** of the containment tank **302** to vent exhaust gases from the drying chamber **310**. A temperature sensor **317** is positioned within the exhaust port **316** to monitor the temperature of an exhaust flow F_6 from the drying chamber **310**.

In operation, the de-watered abrasive **144A** enters the drying chamber **310** through the de-watered abrasive inlet **304** and mixes with the layer of drying abrasive **315**. The blower **338** forces the flow of heating air **336** into the lower heater chamber **330** and over the heater elements **332**. The heating airflow **336** is heated by the heater elements **332** and passes through the porous floor partition **320**. The heating airflow **336** then passes through the layer of drying abrasive **315** in the drying chamber **310**. During this operation, the layer of drying abrasive **315** becomes a hot, fluidized layer and is heavily agitated by the heating airflow **336**.

As damp de-watered abrasive **144A** is introduced into the drying chamber **310**, the level of the layer of abrasive **315** in the first drying section **309A** continues to rise to the top of the first path control wall **308**. The larger and damper clumps of de-watered abrasive **144A** sink to the bottom of the layer of abrasive **315** and are reduced in size. As the de-watered abrasive **144A** dries, it rises to the surface of the layer of abrasive **315** and works its way over the notches **314** of the path control walls **308** into the next drying section **309**. In this embodiment, the notches **314** in the path control walls **308** are positioned at alternating sides of the containment tank **302** in a "labyrinth" arrangement to increase the travel path of the de-watered abrasive **144A** through the drying chamber **310**.

The heating airflow **336** passes through the layer of abrasive **315**, separating and removing the residual, interstitial moisture contained within the de-watered abrasive **144A**. The heating airflow **336** and residual moisture vapor form the wet exhaust flow F_6 that exits from the drying chamber **310** through the exhaust port **316**. The de-watered abrasive **144A** is dried to form a dried abrasive **144B** that exits from the drying chamber **310** via the dried abrasive outlet **306**.

FIG. **11** is a partially sectional isometric view of an embodiment of a vacuum transport system **400** of the abrasive recovery apparatus **100** of FIG. **2**. The vacuum transport system **400** includes a dried abrasive receptacle **402** that receives and contains the dried abrasive **144B** from the dried abrasive outlet **306** of the dryer unit **300**. A vacuum pickup **404** is partially inserted into the dried abrasive **144B** within the dried abrasive receptacle **402**. A standoff housing **406** surrounds the vacuum pickup **404** and is also partially inserted into the dried abrasive **144B** within the dried abrasive receptacle **402**. A vacuum line **408** couples the vacuum pickup **404** to a vacuum pump **410**, and the vacuum pump **410** is coupled to a vacuum exhaust outlet **411**. An abrasive catch vessel **412** is coupled with the vacuum line **408** between the vacuum pickup **404** and the vacuum pump **410**. The abrasive catch vessel **412** is equipped with an outlet valve **414** that controllably releases the dried abrasive **144B** into a storage vessel **416**.

The vacuum pump **410** pulls a vacuum in the vacuum line **408** and vacuum pickup **404**, drawing a flow of transport air F_7 and dried abrasive **144B** out of the dried abrasive receptacle **402** and into the vacuum line **408**. As the vacuum pickup **404** withdraws the dried abrasive **144B** from the dried abrasive receptacle **402**, an approximately conical depression **407** is formed at the lower end of the standoff housing **406**. The flow of transport air F_7 and dried abrasive **144B** is drawn through the vacuum line **408** and is deposited into the abrasive catch vessel **412**. The outlet valve **414** periodically opens to release the dried abrasive **144B** into the storage vessel **416**. The flow transport air F_7 passes through the vacuum pump **410** and exits through the vacuum exhaust outlet **411**.

The vacuum transport system **400** advantageously maintains the performance of the vacuum pickup **404** for remov-

ing the dried abrasive **144B** despite variations in the level of the dried abrasive **144B** within the dried abrasive receptacle **402**. The performance of the vacuum pickup **404** is achieved when the vacuum pickup **404** is maintained at a close standoff distance from the surface of the dried abrasive **144B**. If the vacuum pickup **404** is too far from the surface of the dried abrasive **144B**, none of the dry abrasive **144B** will be transported. If the vacuum pickup **404** is too close to the surface of the dried abrasive **144B**, the vacuum pickup **404** will clog. To overcome the problem presented by variations in the level of the dried abrasive **144B**, the standoff housing **406** is positioned proximate the vacuum pickup **404** to maintain the desired close standoff distance between the surface of the dried abrasive **144B** and the vacuum pickup **404**. The angle of the conical depression **407** is controlled by the angle of repose of the dried abrasive **144B** as the dried abrasive **144B** tumbles into the conical depression **407**. By adjusting the position of the standoff housing **406** relative to the vacuum pickup **404**, the desired close standoff distance is maintained.

FIG. **12** is a flowchart representation of an embodiment of a process **500** for operating the abrasive recovery apparatus **100** of FIG. **2**. In this embodiment, the operating process **500** includes starting the main pump of the abrasive jet cutting system **502**. Next, the fluid drive system of the abrasive-laden fluid handling system is started **504**. The flow of teeter fluid to the hydro-classifier is also started **506**.

After these systems are started, the pressure in the hydro-classifier is monitored, and a determination is made whether the pressure in the hydro-classifier has reached a certain percentage ($X\%$) of a predetermined threshold pressure **508**. The predetermined threshold pressure is the pressure at which the hydro-classifier is considered to be "full" of wet recovered abrasive and the wet recovered abrasive outlet of the hydro-classifier needs to be opened.

If the pressure in the hydro-classifier has not reached the certain percentage ($X\%$) of the predetermined threshold pressure **508**, then a determination is made whether the main pump of the abrasive-jet cutting system is still on **510**. If the main pump is not running, then the teeter fluid flow is shut off, and the abrasive-laden fluid handling system is also shut off **512**. The teeter fluid flow and the abrasive-laden fluid handling system may be shut off simultaneously or successively. Operation of the abrasive recovery apparatus is then complete **514**. If the main pump is not shut off and is still running **510**, however, the offering process continues to monitor the pressure in the hydro-classifier **508**.

When the pressure in the hydro-classifier has reached the certain percentage ($X\%$) of the predetermined threshold pressure **508**, then a determination is made whether the dryer unit has been started **516**. If not, the dryer unit is started by turning on the heater elements and the blower **518**. The heater elements may be adjustably controlled until a temperature of the exhaust flow F_6 the dryer unit reaches a desired exhaust flow temperature.

Next, it is determined whether the main pump of the abrasive jet cutting system is still on **520**. If the main pump is still on, a determination is made whether the pressure in the hydro-classifier has reached 100% of the predetermined threshold pressure **522**. If the pressure has not reached the predetermined threshold pressure, the operating process returns to the monitoring of the pressure in hydro-classifier **508**.

If the main pump is not still on **520**, or if the main pump is still on **520** and the pressure in the hydro-classifier has reached 100% of the predetermined threshold pressure **522**,

the wet recovered abrasive is dumped from the hydro-classifier via the wet abrasive outlet into the wet abrasive receptacle **524**. After the wet recovered abrasive is dumped, the de-watering device is operated until the wet recovered abrasive has been dewatered and transported into the dryer unit **526**. Next, the exhaust temperature of the dryer unit is monitored **528**.

Based on the exhaust temperature of the dryer unit, the determination is made whether evaporation in the dryer unit is complete **530**. This may be accomplished in various ways, including by monitoring the time history of the exhaust temperature. For example, the initial exhaust temperature may be the desirable exhaust temperature prior to entry of the de-watered abrasive into the dryer unit. As the de-watered abrasive enters dryer unit, the exhaust temperature may drop due to the evaporation of residual fluid in the de-watered abrasive. After a period within the dryer unit, the exhaust temperature may then rise again to the desirable exhaust temperature, indicating that the residual, interstitial fluid within the de-watered abrasive has been removed, and the drying of the de-watered abrasive is complete.

If the evaporation in the dryer unit is not complete **530**, the exhaust temperature of the dryer unit continues to be monitor **528**. After the evaporation in the dryer unit is complete **530**, the dryer unit shuts off **532**. The determination is then made whether the main pump of the abrasive jet cutting system is still on **534**. If it is, the operating process returns to the monitoring of the pressure in the hydro-classifier **508**, and a process is repeated. If, however, the main pump is not still on **534**, the teeter fluid flow to shut off and the abrasive-laden fluid handling system to shut off **512**, and the operating process is terminated **514**.

Generally, the predetermined threshold pressure for considering the hydro-classifier to be full of wet recovered abrasive, the certain pressure (X%) at which the dryer unit is turned on, and the desired exhaust temperature of the dryer unit are all system specific characteristics. The actual values of these parameters that may be used in the operating process **500** may depend on several system specific variables, including, for example, the dimensions of the components (e.g., the hydro-classifier) of the abrasive recovery apparatus **100**, the operating conditions of the abrasive jet cutting system, the type of abrasive and cutting fluid being used, the power and efficiency of the dryer unit, and other variables.

Several aspects of the operating process **500** advantageously save energy and reduce operating costs compared with the prior art process. For example, because the dryer unit is not started until the pressure in the hydro-classifier has achieved the certain percentage (X%) of the predetermined threshold pressure, energy savings are realized. Also, by monitoring the exhaust temperature from the dryer unit and shutting off the dryer unit when evaporation is complete, additional energy savings are achieved. In addition, the de-watering device is operated selectively rather than continuously, and is used only when necessary to de-water and transport the wet recovered abrasive from the wet recovered abrasive receptacle to the dryer unit. Finally, the operating process contains several steps to determine whether the main pump of the abrasive jet cutting system is still on, and shuts the abrasive recovery apparatus down automatically when the abrasive-jet cutting system is shut down.

An abrasive recovery apparatus **600** provided in accordance with an alternative, preferred embodiment of the present invention is illustrated in FIGS. **13–18**. Several of

the components of the system are the same in design and function as those described with respect to the abrasive recovery apparatus **100** of FIG. **2**. Where system components are alike, same reference numbers are used, and those components will not be described again in the discussion below of the abrasive recovery apparatus **600**.

In a preferred embodiment, the abrasive recovery apparatus **600** includes a plurality of abrasive-laden fluid handling devices **612**. The number of handling devices **612** is dependent on the size of catcher tank **16**. As best seen in FIG. **14**, each of the abrasive-laden fluid handling devices **612** is positioned at least partially within a catcher tank **16**. The handling device **612** includes a conduit **613** coupled to a fluid eduction assembly **614**. The fluid eduction assembly **614** includes a fluid eductor **615** coupled to a source of fluid via intake **618**. The eduction assembly **614** causes fluid to flow through the conduit **613**, generating a vacuum that entrains abrasive-laden fluid from the catcher tank **16** into the conduit **613** through an inlet **617**. Inlet **617** is in fluid communication between the catcher tank **16** and the conduit **613**. A screen **619** is positioned adjacent the inlet **617** to prevent debris from entering the conduit **613**. In this manner, the fluid eduction assembly **614** causes abrasive-laden fluid to flow from the catcher tank **16** upward through the conduit **613** and out of the abrasive-laden fluid outlet **620**. Depending on the size of the catcher tank, a selected number of handling devices **612** will be positioned within the catcher tank at selected locations. The flow of abrasive-laden fluid from each of the fluid outlets **620** is directed into an associated inlet **610** of a hydro-classifier **130**. By using fluid eduction in accordance with a preferred embodiment of the present invention to remove abrasive-laden fluid from the catcher tank, the concentration of abrasive is increased, eliminating the need for a pre-classifier **120**, while still allowing the use of a smaller hydro-classifier **130**, as compared to conventional systems.

The hydro-classifier **130** of the abrasive recovery apparatus **600** functions as described previously. However, as illustrated in FIG. **15**, the hydro-classifier includes a monitoring system **621**, further comprising a fluid eductor **622** coupled to a bottom region of the hydro-classifier adjacent valve **623**. A pressure transducer **624** monitors the pressure in the hydro-classifier, and generates a first signal to open the valve **623** and activate the fluid eductor **622** to transport wet abrasive from the wet abrasive outlet of the hydro-classifier to a wet abrasive intake **627** of a de-watering device **625**. When valve **623** is open and the eductor **622** of the hydro-classifier is activated, the fluid educators **615** on the abrasive-laden fluid handling devices **612** are deactivated, to prevent the further flow of abrasive fluid to the hydro-classifier. In response to a second predetermined, measured pressure level in the hydro-classifier, the pressure transducer generates a second signal to close the valve **623** and deactivate the fluid eductor **622**, thereby stopping the flow of wet abrasive to the de-watering device **625**. Eductors **615** are also reactivated, again causing abrasive-laden fluid to flow to the hydro-classifier. In this manner, a selected quantity of wet abrasive is delivered to the de-watering device **625** in batches.

As illustrated in FIGS. **16–18**, the de-watering device **625** includes a housing **626** provided with a collection tube **631**. The collection tube **631** is in fluid communication with a wet abrasive intake **627** and a de-watered abrasive outlet **628**. As best seen in FIGS. **16** and **17**, the collection tube **631** is positioned in a substantially vertical position **639**, such that as the wet abrasive is provided to the de-watering device **625**, the abrasive collects in a bottom region of the collection

tube 631 adjacent a screen 637. Fluid 641 from the wet abrasive collects substantially above the abrasive as the abrasive settles in the bottom region of the collection tube 631. If the water level in the collection tube 631 reaches the top of the tube as the device is filling with wet abrasive, the fluid 641 is free to flow out of the outlet 628 into a sump 638.

Once a selected amount of wet abrasive 629 has been provided to the collection tube 631, and the flow of wet abrasive to the de-watering device 625 has been stopped, as described previously, a valve 632 is opened to decant the fluid 641 from the collection tube 631. A screen 633 is positioned adjacent the decanting valve 632 to substantially prevent abrasive from exiting the de-watering device via valve 632. The de-watering device 625 further includes an eduction system 630 having an air eductor 635 and a second valve 634 in fluid communication with a source of pressurized fluid, such as air. Once the first decanting valve 632 is open for a predetermined period of time, the air eductor 635 is activated, thereby drawing air through the abrasive to remove interstitial moisture from the abrasive. The air eductor 635 may be controlled automatically, being activated for a set amount of time. The de-watering device 625 therefore removes water from the abrasive in two stages, by decanting water via the first valve 630 and by forcing air through the abrasive via an air eductor 635.

After this two step de-watering process is complete, a slug 636 of de-watered abrasive is positioned in the bottom region of collection tube 631. The collection tube 631 is rotated to a substantially horizontal position 640, and the slug 636 is ejected from the tube 631 via pressurized air provided through valve 634. In this manner, the screen 637 at the bottom of the collection tube 631 is backflushed, to remove abrasive from the screen. The slug 636 is discharged to the entrance of a dryer unit 300, and dried and further processed as described above with respect to abrasive recovery apparatus 100. The collection tube 631 is then rotated to a substantially vertical position 639 to receive another volume of wet abrasive. As the tube 631 is being returned to a vertical position, air may be flushed through the valve 632 to clear screen 633 and improve the efficiency of the next decanting cycle.

In a preferred embodiment, a pump on the sump 638 provides fluid to the fluid eductors 615 of the fluid handling devices 612 and to the fluid eductor 622 of the hydro-classifier. When the level of fluid in the sump 638 exceeds a pre-selected level, all of the fluid eductors 615 and 622 are deactivated, and a valve on the sump is opened to siphon off extra fluid back to the catcher tank 16. In this manner, the system is self-contained. In addition, an abrasive recovery apparatus 600 provided in accordance with a preferred embodiment of the present invention is cost effective to manufacture, and eliminates wear items, such as an auger.

Improved apparatus and methods for recovering abrasive from an abrasive-laden fluid for use with abrasive jet cutting systems have been shown and described. From the foregoing, it will be appreciated that although embodiments of the invention have been described herein for purposes of illustration, various modifications may be made without deviating from the spirit of the invention. Thus, the present invention is not limited to the embodiments described herein, but rather is defined by the claims which follow.

What is claimed is:

1. An abrasive recovery apparatus for use with an abrasive-jet cutting system including a catcher tank, comprising:

an abrasive-laden fluid handling device having an abrasive-laden fluid conduit at least partially disposed within the catcher tank and an abrasive-laden fluid outlet;

a hydro-classifier fluidly coupled to the abrasive-laden fluid outlet, the hydro-classifier having a teeter fluid inlet couplable to a fluid source providing a teeter fluid flow that mixes with a flow of abrasives from the abrasive-laden fluid outlet to form a fine particle flow and a wet abrasive, the hydro-classifier having a fine particle flow outlet and a wet abrasive outlet;

a de-watering device including a housing having a wet abrasive intake and a de-watered abrasive outlet, the wet abrasive intake being coupled to the wet abrasive outlet of the hydro-classifier to receive the wet abrasive, the housing being coupled to an eduction system, the eduction system selectively drawing air through the wet abrasive to remove interstitial moisture from the wet abrasive resulting in de-watered abrasive; and

a dryer unit having a de-watered abrasive inlet positioned to receive the de-watered abrasive from the de-watered abrasive outlet, the dryer unit having a heating element and a dried-abrasive outlet.

2. The abrasive recovery apparatus according to claim 1 wherein the abrasive-laden fluid handling device further comprises a fluid eduction assembly coupled to a source of fluid and an inlet in fluid communication with the catcher tank and with the abrasive-laden fluid conduit, a volume of fluid being drawn through the conduit by the fluid eduction system to generate a vacuum at the inlet and entrain and transport abrasive-laden fluid from the catcher tank through the inlet and conduit to the abrasive-laden fluid outlet.

3. The abrasive recovery apparatus according to claim 2, further comprising a screen provided on the inlet to prevent contaminants larger than a selected size from entering the conduit.

4. The abrasive recovery apparatus according to claim 1, further comprising a monitoring system, the monitoring system stopping the flow of wet abrasive to the housing of the de-watering device when it reaches a pre-selected level within the housing.

5. The abrasive recovery apparatus according to claim 4 wherein the monitoring system is coupled to the hydro-classifier and generates a first signal to open a first valve positioned between the wet-abrasive outlet of the hydro-classifier and the wet-abrasive intake of the de-watering device and to activate an eductor positioned adjacent the first valve to transport wet abrasive from the hydro-classifier to the de-watering device, and generates a second signal to close the first valve and deactivate the eductor to selectively prevent the transport of wet abrasive to the de-watering device.

6. The abrasive recovery apparatus according to claim 5 wherein the monitoring system includes a pressure transducer that senses the pressure in the hydro-classifier, the first and second signals being generated by the pressure transducer in response to the pressure in the hydro-classifier.

7. The abrasive recovery apparatus according to claim 4 wherein a portion of the housing forms a collection tube in which the wet abrasive collects, the collection tube being movable from a first substantially vertical position to a second substantially horizontal position, a second valve coupled to the housing selectively allowing fluid to decant off of the wet abrasive and a third valve coupled to the housing selectively allowing the eduction system to draw air through the wet abrasive while the collection tube is in the substantially vertical position, a plug of de-watered abrasive being ejected from the collection tube by a pressurized stream of air forced into the housing via the third valve.

8. A method of recovering abrasive from an abrasive-laden fluid contained within a catcher tank of an abrasive jet cutting system, comprising:

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removing abrasive-laden fluid from the catcher tank;
 separating the abrasive-laden fluid into a wet recovered
 abrasive and a fine particle flow;
 de-watering the wet recovered abrasive to form a
 de-watered abrasive; 5
 drying the de-watered abrasive to form a dry recovered
 abrasive; and
 generating a flow of fluid through a conduit positioned in
 the catcher tank via a fluid eductor to entrain abrasive- 10
 laden fluid from the catcher tank into the flow of fluid
 through the conduit.

9. A method of recovering abrasive from an abrasive-
 laden fluid contained within a catcher tank of an abrasive jet
 cutting system, comprising:

removing abrasive-laden fluid from the catcher tank;
 separating the abrasive-laden fluid into a wet recovered
 abrasive and a fine particle flow;
 de-watering the wet recovered abrasive to form a
 de-watered abrasive; 20
 drying the de-watered abrasive to form a dry recovered
 abrasive;
 filling a collection tube with wet recovered abrasive to a
 pre-selected level; 25
 stopping the flow of wet recovered abrasive to the col-
 lection tube;
 decanting fluid off of the wet recovered abrasive out of the
 collection tube;

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drawing air through the wet recovered abrasive to further
 de-water the abrasive thereby generating a slug of
 de-watered abrasive; and

ejecting the slug from the collection tube to a dryer.

10. The method according to claim **9**, further comprising:
 measuring the pressure in a hydro-classifier that separates
 the abrasive-laden fluid into the wet recovered abrasive
 and the fine particle flow; and

allowing wet recovered abrasive to flow to the collection
 tube in response to a first predetermined pressure
 reading and preventing the flow of wet recovered
 abrasive to the collection tube in response to a second
 predetermined pressure reading.

11. The method according to claim **10**, further compris-
 15 ing:

selectively opening and closing a valve of the hydro-
 classifier and selectively activating and deactivating an
 eductor coupled to the hydro-classifier in response to
 the measured pressure in the hydro-classifier.

12. The method according to claim **9**, further comprising
 backflushing a screen through which fluid is decanted off of
 the wet recovered abrasive.

13. The method according to claim **9**, further comprising:
 tilting the collection tube from a substantially upright
 position to a substantially horizontal position prior to
 ejecting the slug of de-watered abrasive from the
 collection tube.

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